Green Connections : A Network Economics Approach to the Energy Transition

Côme Billard

Thèse de doctorat en Sciences Économiques,
Préparée sous la direction d’Anna Creti.

Laboratoire d’économie de l’Université Paris-Dauphine / Chaire Économie du Climat.

Soutenance de thèse - Jeudi 3 Décembre 2020
Motivations (I)

- To limit global warming to less than 2°C by the end of the century, economies worldwide must reach carbon neutrality by 2050 ([IPCC, 2018](#));

- Large-scale diffusion of low-carbon technologies represents an important component of international strategies to achieve such a target, largely driven by environmental policies ([Grantham Research Institute, 2018; OECD, 2018](#)).

- Green transition is about diffusion of technologies, policies and ... economic shocks.
How could *Network Economics* enhance our understanding of diffusion processes? What insights can be drawn from a policy-making perspective?

- Network Economics (e.g. Acemoglu, Bromley-Trujillo et al., Beaman, Centola, Jackson, Lim and Teytelboym);

- Environmental Economics (e.g. Farmer and Lafond, Halleck-Vega and Mandel, Godin et al.).
Structure of the Manuscript

- **Chapter 1**: *Network Structures, Environmental Technology and Social Contagion* *(Forthcoming in *Climate Policy)*;


- **Chapter 3**: *Triggering Reduction of Imported Emissions in the E.U.* with A. Creti;

- **Chapter 4**: *COVID-19 Recovery Packages and Industrial Emission Rebounds: Mind the Gap.* with A. Creti.
Chapter 1

Network Structures, Environmental Technology and Social Contagion

Forthcoming in *Climate Policy*
1: Network Structures, Environmental Technology and Social Contagion

Context:

- Collective behaviors spread through social contact (e.g. solar PV adoption, alternative fuel vehicle; see Bollinger and Gillingham, 2012; Richter, 2013; Jansson et al., 2017);

- Social networks: pathways in which «social contagion» propagates (Baranzini et al., 2017; Becker et al., 2018);

- Simple Contagion (epidemics) vs Complex Contagion (innovation) (Centola & Macy, 2007).
1: Network Structures, Environmental Technology and Social Contagion

- Research question: *How network structures influence the contagion of a costly clean innovation?*

- Methodology: Agent Based Model

- Neighborhood threshold + Cost threshold;
- Learning Effects / Network structures.

*Lattice*  \[\rightarrow\]  *Small-World*  \[\rightarrow\]  *Random*
1: Network Structures, Environmental Technology and Social Contagion

Results (1): Aggregate diffusion as a function of initial seeds.
1 : Network Structures, Environmental Technology and Social Contagion

Results (2) : Diffusion heterogeneity measured by variance.
Concluding remarks & policy implications

- Clustering favours diffusion;
  - Encouraging connections + social platforms?

- Clustered networks display higher diffusion variance;
  - The case of uncertainty...

- Learning effects: higher diffusion, larger aggregate gap;
  - Supporting the «good» technology!
Chapter 2

How do Environmental Policies Spread? A Network Approach to Diffusion in the U.S.

Joint work with Anna Creti and Antoine Mandel (Université Paris-I / PSE)

FAERE Working Paper / Climate Economics Chair Working Paper
American Context:

- Federalism, a peculiar environment for policy diffusion (Berry and Berry, 1990; Pitt, 2010);

- Policies regularly spread throughout the American states, driven by underlying forces (i.e. competitive, cooperative, and imitative);

- Determinants: citizens ideology, partisan control of the state, state's economy, geographic proximity (Matisoff, 2008; Huang et al., 2007; Matisoff and Edward, 2014; Berry & Berry, 1992).
2 : How Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.

- Research question : Are there pathways of environmental policy transmission across U.S. states ? What are the determinants of such observations ?

- Methodology :

  1. Independant Cascade Model to infer a network from series of observations, i.e. cascades \((Gomez-Rodriguez, 2010; Halleck-Vega et al, 2018)\); (2) Logistic model;

- Dataset : 74 policies, 51 states, 1974/2018, three initial databases.
2 : How Environmental Policies Spread? A Network Approach to Diffusion in the U.S.

2 : How Environmental Policies Spread ? A Network Approach to Diffusion in the U.S.

**Results (2) : Central States vs Less integrated states.**

**Central States**

<table>
<thead>
<tr>
<th>Minnesota</th>
<th>Minnesota</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>California</td>
</tr>
<tr>
<td>Florida</td>
<td>Utah</td>
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<tr>
<td>Pensylvannia</td>
<td>Hawai</td>
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<tr>
<td>New York</td>
<td>Missouri</td>
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<tr>
<td>Wisconsin</td>
<td>Florida</td>
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<tr>
<td>West Virginia</td>
<td>Washington</td>
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<td>Wyoming</td>
<td>Colorado</td>
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<tr>
<td>Arizona</td>
<td>Rhode Island</td>
</tr>
<tr>
<td>District of Columbia</td>
<td>Alaska</td>
</tr>
<tr>
<td>Alaska</td>
<td>South Carolina</td>
</tr>
<tr>
<td>South Dakota</td>
<td>District of Columbia</td>
</tr>
</tbody>
</table>

**Mapping Leaders/Followers**

Green Connections : A Network Economics Approach to the Energy Transition
2 : How Environmental Policies Spread? A Network Approach to Diffusion in the U.S.

Results (3) : Determinants of transmission policy pathways.

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>T-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contiguity (Relationship)</td>
<td>1.69**</td>
<td>(41.09)</td>
</tr>
<tr>
<td>GDP per capita (Source)</td>
<td>0.03**</td>
<td>(4.60)</td>
</tr>
<tr>
<td>Population Density (Source)</td>
<td>-0.49**</td>
<td>(-28.78)</td>
</tr>
<tr>
<td>States Governors Party</td>
<td>-0.03**</td>
<td>(-4.71)</td>
</tr>
<tr>
<td>Federal Government Party</td>
<td>-0.00</td>
<td>(-0.62)</td>
</tr>
<tr>
<td>Citizen Ideology</td>
<td>-0.00**</td>
<td>(-9.00)</td>
</tr>
<tr>
<td>Climate change Economic Impacts (&gt;5% GDP)</td>
<td>-0.34**</td>
<td>(-21.04)</td>
</tr>
<tr>
<td>Genuine Progress Indicator (source)</td>
<td>0.51**</td>
<td>(33.84)</td>
</tr>
<tr>
<td>Coal Mining State (Source)</td>
<td>-0.04**</td>
<td>(-2.69)</td>
</tr>
</tbody>
</table>

- **Contiguity** : the odds of transmission are **5.41** higher compared to the reference category;
- **GDP Per capita** : increases the odds of transmission;
- **Climate change Economic Impacts** : odds of transmission are lower compared to the reference category;
- **GPI** : green economic system increases the odds of transmission.
Concluding remarks & policy implications

- Inefficient network organization (Minnesota, California, Florida vs. South Dakota, South Carolina, Alaska).
  - Targeting specific states to maximize diffusion;

- NorthEastern States display highly concentrated diffusion;
  - Suggests different areas / dynamics of diffusion;

- Contiguity, GPI, expected climate change economic losses;
  - Vulnerability does not imply transmission!

Green Connections : A Network Economics Approach to the Energy Transition
Chapter 3

Triggering Reduction of Imported Emissions in the E.U.

Joint work with Anna Creti

Green Connections : A Network Economics Approach to the Energy Transition
3: Triggering Reduction of Imported Emissions in the E.U.

-European context: Green Deal (2019)

- Jump from 40% to 50% GHGs emission reduction objective; Net Zero by 2050;
- Tackling the issue of imported Emissions;
- Disconnection between territorial and consumption-based emissions (e.g. UK, 2014; France, 2018).
3 : Triggering Reduction of Imported Emissions in the E.U.

- Research question : What about the *dynamics of demand and supply of dirty imports* within an economy? *And the specific role of sectors in reducing such patterns?*

- Methodology :
  
  - (1) Input Output Tables, Imports distribution, Ghosh Matrix, Imported Emissions, Networks;
  
### 3: Triggering Reduction of Imported Emissions in the E.U.

**Results (1): Emission Reduction Coefficients.**

<table>
<thead>
<tr>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
<th>Poland</th>
<th>U.K.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Emission Reduction Multipliers (2)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mining A (0.0689)</td>
<td>Mining A (0.0089)</td>
<td>Mining B (0.0081)</td>
<td>Mining A (0.0012)</td>
<td>Mining A (0.0004)</td>
</tr>
<tr>
<td>Mining C (0.0034)</td>
<td>Mining B (0.0018)</td>
<td>Mining A (0.0024)</td>
<td>Basic metals (0.0005)</td>
<td>Mining B (0.0004)</td>
</tr>
<tr>
<td>Mining B (0.0002)</td>
<td>Mining C (0.0008)</td>
<td>Mining C (0.0008)</td>
<td>Mining B (0.0004)</td>
<td>Basic metals (0.0003)</td>
</tr>
<tr>
<td>Basic metals (0.0001)</td>
<td>Basic metals (0.0001)</td>
<td>Basic metals (0.0002)</td>
<td>Chemicals (0.0003)</td>
<td>Electrical eq. (0.0003)</td>
</tr>
<tr>
<td>Electrical eq. (0.0001)</td>
<td>Coke-refined petrol. (0.0001)</td>
<td>Chemicals (0.0001)</td>
<td>Machinery &amp; eq. (0.0003)</td>
<td>Computer-electronics (0.0002)</td>
</tr>
</tbody>
</table>

| **Exposure to Emission Reduction Multipliers (3)** |                  |                  |                  |                  |
| Coke & refined petrol. (0.0420) | Coke & refined petrol. (0.0053) | Basic metals (0.0068) | Basic metals (0.0009) | Other manufacturing (0.0004) |
| Electricity & gas (0.0222) | Basic metals (0.0026) | Coke-refined petrol. (0.0010) | Electricity-gas (0.0006) | Basic metals (0.0004) |
| Chemicals (0.0027) | Chemicals (0.0011) | Mining A (0.0009) | Electrical eq. (0.0003) | Coke-refined petrol. (0.0003) |
| Construct. (0.0026) | Electricity & gas (0.0009) | Chemicals (0.0008) | Machinery-eq. (0.0003) | Other transport eq. (0.0002) |
| Basic metals (0.0011) | Mining A (0.0007) | Other non-met. min. (0.0007) | Coke-refined petrol. (0.0003) | Electrical eq. (0.0002) |
3 : Triggering Reduction of Imported Emissions in the E.U.

Results (2) : Hierarchical network of imported emission reduction cascades across economic sectors in France.
3: Triggering Reduction of Imported Emissions in the E.U.

- Strongest immediate emission reductions:
  - Coke and Refined Petroleum Products (C19) (France, Germany, Poland, U.K.);
  - Basic metals (C24) - well connected! (Germany, Italy, Poland);
    - Fabricated metal products, machinery and equipment, electrical equipment, motor vehicles and other transport equipment
  - Electricity and Gas (D-E) (France, Germany, Poland, U.K.)
3 : Triggering Reduction of Imported Emissions in the E.U.

Concluding remarks & policy implications

- We can identify relevant cascades - but differences across E.U. countries!
  - Different levels of trade exposure across EU economies;
- Basic Metals is a huge supplier for other industrial sectors (e.g. Germany);
  - Taxing imported carbon from basic metals —> disparities across countries —> compensation/exposure?

Joint work with Anna Creti
European context:

- 81% of the global workforce hit by lockdown measures (International Labour Office, 2020); Consumer spending has fallen - restrictions (to travel, to shop for discretionary items, go to restaurants, or for experience-based activities (Center for Economic Policy Research, 2020));

- 2020: A contraction of 7.4 per cent in the EU economy (European Commission, 2020);

- Recovery plans could be either "brown" or "green" (IFRI, 2020).
Research question: What about the dynamics of demand and supply of dirty products within an economy? And the specific role of sectors in reducing such patterns?

Methodology:

1. Input Output Tables, Ghosh Matrix and Emissions, cascades/networks;

Dataset: France, Germany, Italy, Poland, Spain, OECD - 2015.
4: COVID-19 Recovery Packages and Industrial Emission Rebounds: Mind the Gap

Results (1): Emission Reduction Coefficients.

<table>
<thead>
<tr>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
<th>Poland</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining (0.0287)</td>
<td>Mining (0.0178)</td>
<td>Mining (0.0359)</td>
<td>Mining (0.0088)</td>
<td>Mining (0.0280)</td>
</tr>
<tr>
<td>Electricity &amp; gas (0.0004)</td>
<td>Coke &amp; petrol. (0.0008)</td>
<td>Prof., Scient., Techn. act. (0.0007)</td>
<td>Chemicals (0.0019)</td>
<td>Chemicals (0.0008)</td>
</tr>
<tr>
<td>Coke &amp; refined petrol. (0.0004)</td>
<td>Wholesale retail trade (0.0005)</td>
<td>Financ. services (0.0007)</td>
<td>Coke &amp; refined petrol. (0.0016)</td>
<td>Electricity &amp; gas (0.0008)</td>
</tr>
<tr>
<td>Rubber &amp; plastics (0.0004)</td>
<td>Prof., Scient., Techn. act. (0.0004)</td>
<td>Basic metals (0.0006)</td>
<td>Basic metals (0.0015)</td>
<td>Rubber &amp; plastics (0.0007)</td>
</tr>
<tr>
<td>Fab. metal (0.0004)</td>
<td>Fab. metal (0.0004)</td>
<td>Coke &amp; refined petrol. (0.0006)</td>
<td>Machinery &amp; eq. (0.0013)</td>
<td>Financ. services (0.0006)</td>
</tr>
</tbody>
</table>

External Emission Reduction Multipliers (2)

<table>
<thead>
<tr>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
<th>Poland</th>
<th>Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke &amp; petrol. (0.0225)</td>
<td>Electricity &amp; gas (0.0114)</td>
<td>Coke &amp; petrol. (0.0268)</td>
<td>Electricity &amp; gas (0.0142)</td>
<td>Coke &amp; petrol. (0.0205)</td>
</tr>
<tr>
<td>Electricity &amp; gas (0.0042)</td>
<td>Coke &amp; petrol. (0.0083)</td>
<td>Electricity &amp; gas (0.0141)</td>
<td>Coke &amp; petrol. (0.0058)</td>
<td>Electricity &amp; gas (0.0104)</td>
</tr>
<tr>
<td>Basic metals (0.0029)</td>
<td>Basic metals (0.0036)</td>
<td>Basic metals (0.0026)</td>
<td>Agricult. (0.0053)</td>
<td>Basic metals (0.0039)</td>
</tr>
<tr>
<td>Agricult. (0.0026)</td>
<td>Agricult. (0.0017)</td>
<td>Agricult. (0.0017)</td>
<td>Basic metals (0.0029)</td>
<td>Oth. non-met. min. (0.0031)</td>
</tr>
<tr>
<td>Oth. non-met. min. (0.0012)</td>
<td>Oth. non-met. min. (0.0017)</td>
<td>Chemicals (0.0009)</td>
<td>Oth. non-met. min. (0.0021)</td>
<td>Agricult. (0.0015)</td>
</tr>
</tbody>
</table>

Exposure to Emission Reduction Multipliers (3)
4: COVID-19 Recovery Packages and Industrial Emission Rebounds: Mind the Gap

Results (2): Hierarchical network of emission reduction cascades across economic sectors in France.
4: COVID-19 Recovery Packages and Industrial Emission Rebounds: Mind the Gap

- Concluding remarks & policy implications
  - Electricity & gas / Coke and refined petroleum products largely depend on dirty inputs (Germany, Poland);
  - Chemicals as well as basic metals have significant impacts on emissions too;
    - EU Recovery Packages should ensure these sectors to divest;
    - Carbon pricing to create incentives to shift from dirty to clean inputs?
  - Common patterns of cascades across EU countries;
    - Regional strategy to clean carbon-intensive sectors?

Green Connections: A Network Economics Approach to the Energy Transition

Côme Billard - Ph.D. Candidate - Paris-Dauphine University
General Conclusion

- **Chapter 1**: *The structure of underlying social networks is key in the diffusion of clean technologies*;
  - The disclosure of social data to target clusters;

- **Chapter 2**: *The location of agents in the networks is fundamental to capture diffusion patterns across U.S. states*;
  - Targeting key states to foster diffusion;

- **Chapter 3 and Chapter 4**: *Neighborhood connections matter when it comes to economic interactions*;
  - Connectedness = Exposure of sectors...
Thank you for your attention!
Green Connections: A Network Economics Approach to the Energy Transition

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Soutenance de thèse - Jeudi 3 Décembre 2020
Appendices
From Networks to Diffusion (1)

- Node: One of many points in a Network;
- Edge: Link connecting nodes in a Network;
- Network: A set of nodes and edges.

- Applications: Social networks (e.g., Pierri et al., 2020), banking system (Battiston et al., 2016), epidemics (Block et al., 2020).

- Diffusion... processes are not equivalent!

- Epidemics ≠ Technology; Idea ≠ Behaviors ≠ Policies etc...
Chapter 1
INTRODUCTION
Basics and Generalities on Networks

- Recap on definitions:
  - Node: One of many points (eg. agents) in a Network;
  - Edge: Vertices connecting nodes in a Network;
  - Network: A set of Nodes (eg. agents) and Edges (eg. relationships).

- Possible applications:
  - Social networks, Viral marketing, Rumors, Internet, Bank failures systemic risks, Technology etc...
Context (1) - Contagions in Networks

- Different dynamics of diffusion: epidemics ≠ technology, idea ≠ behaviors etc...

<table>
<thead>
<tr>
<th>Simple contagions</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Simple contagions&quot; require only one contact for transmission (eg. information, disease). Since a connection is &quot;infected&quot;, her contact follows with probability P.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Complex contagions</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Complex contagions&quot; need multiple sources of reinforcement to induce adoption (eg. large range of behaviors). To switch, an agent must have a certain proportion of her contacts who has previously adopted the behavior (Linear Threshold Model (Granovetter, 1978)).</td>
</tr>
</tbody>
</table>

Centola and Macy, 2007.

The role of network’s topology is critical for diffusion: Some underlying structures could favor/hamper diffusion processes.
Main Literature (1) - Diffusion in Networks

- Key observations for simple/complex contagions in clustered/random networks:
  - **Simple contagion**: Short path length favor diffusion (Granovetter, 1974);
  - **Complex contagion**: Clustering is critical (Centola and Macy, 2007; Centola, 2010; Centola, 2018);
  - Useful to cluster seeds in the same part of the network otherwise no one crosses the threshold and we observe no adoption (Beaman, 2018);
Main Literature (2) - Diffusion in Networks

• Clustering fosters diffusion if at least one seed is placed in the community (Acemoglu, 2011);

• Low speed of diffusion under complex contagion — takes time to join different nodes in the network (Delre et al., 2006). Lower in random networks — Lower probability of being exposed to an adopter.

Gap in the literature:

• Questions about products/technologies subject to a cost function?

• Once a costly technology is introduced, how would (irreversible) diffusion occur with respect to clustering and path length?
Main Contributions & Objectives (1)

- This paper contributes to the literature by:

  - Being the first to consider a network based approach to technology diffusion and its associated decreasing cost function (Moore’s Law) - in a complex contagion setting;

  - Extending the original LTM and introducing a second threshold dealing with the associated technology cost function subject to learning effects;

  - Assuming irreversibility to cascade process (ie. diffusion) (Blume, 1993; Ellison, 1993; Montanari ad Saberi, 2010; Adam et al. 2012).
Main Contributions & Objectives (2)

Objectives are:

- Estimating the impacts of clustering, path length and technological learning effect on technology diffusion;

- Comparing aggregate levels of diffusion, associated speeds and time of convergence for the expected number of switches in three classes of finite networks (lattice, SW and random graphs) with any initial seeds.
Model
Networks : Watts Strogatz (1)

- Global clustering : tendency for nodes to form knit groups (ie. cliquishness); Average path length : average distance between two nodes;

- For $N=16$, $k=4$ and $p=$probability of rewiring, we have :

The transition from a locally ordered structure to a disordered one via a small world. 

*Cowan, 2004.*
Networks: Watts Strogatz (2)

Average cliquishness and average path length as function of $p$.

Model : Preliminaries (1)

- Simple, undirected graph $G(V,E)$ with a set of $n$ agents $V := \{1,\ldots, n\}$ and a set of $m$ links $E$;
- Neighbors of $i \in V$ denoted $N_i(G) := \{j|(j,i) \in E\}$ and the degree of $i$ as $d_i := |N_i(G)|$;
- Agent $i$ is assigned two thresholds $\mu_i$ and $\theta_i$, drawn independently, uniformly at random from probability distributions with support $[0, 1]$;
- Define the threshold profile of agents $\mu := (\mu_i), i \in V$ and $\theta := (\theta_i), i \in V$;
- A network $G_{\mu,\theta}$ is a graph endowed with the two thresholds profiles.
Model : Preliminaries (2)

- $C_t$ : cost function of the technology at time $t$, bounded between $[0, 1]$.
- $S_t(G_{\mu, \theta})$ : the set of additional switches in network $G$ at time $t$.
- $\alpha$ : technological learning effect on cost taking the respective values $[0.1; 0.3; 0.5; 0.7]$ - meaning that technology cost decreases from 1 to 0 with respect to the number of adopters $S$.

That is:

$$C_t = C_0 \times (|U_{\tau=0}^{t-1} S_{\tau}|)^{-\alpha}$$
Model: Dynamics (1)

- At time $t = 0$, a subset of agents $S_0 \subseteq V$ is selected as a seed set. We assume that at $t = 0$ agents switch if and only if they are in the seed set.

- Hence, at $t = 1$, any $i \in V \setminus S_0(G_{\mu, \theta})$ will switch, i.e., $i \in S_1(G_{\mu, \theta})$ if:

$$|C_t(S_0(G_{\mu, \theta}))| \leq \mu_i, \quad \text{and} \quad \frac{|S_0(G_{\mu, \theta}) \cap N_i(G_{\mu, \theta})|}{|N_i(G_{\mu, \theta})|} \geq \theta_i.$$  

- Then, for a given period $t \geq 0$ and node $i \in V \setminus \bigcup_{\tau=0}^{t-1} S_\tau$ will switch at $t$, i.e., $i \in S_t(G_{\mu, \theta})$ if:

\begin{align*}
(1) \quad |C_t(\bigcup_{\tau=0}^{t-1} S_\tau(G_{\mu, \theta}))| &\leq \mu_i, \quad \text{and} \quad (2) \quad \frac{|\bigcup_{\tau=0}^{t-1} S_\tau(G_{\mu, \theta}) \cap N_i(G_{\mu, \theta})|}{|N_i(G_{\mu, \theta})|} \geq \theta_i.
\end{align*}
Model: Dynamics (2)

- Necessary Conditions for a global cascade:

  Achieving a global cascade (ie. every agents adopt the technology) requires, for at least one agent \( i \) at each period \( t \), two conditions to hold:

  \[
  (3) \quad \forall t, \exists i \in V \setminus U_{\tau=0}^t S_\tau \text{ such that } \mu_i \geq C_{t+1}
  \]

  \[
  (4) \quad \frac{\left| \bigcup_{\tau=0}^{t-1} S_\tau(G_{\mu,\theta}) \cap N_i(G_{\mu,\theta}) \right|}{|N_i(G_{\mu,\theta})|} \geq \theta_i.
  \]

- For a given network \( G_{\mu,\theta} \), define the fixed point of the process such that:

  \[
  S_0(X) = S(G_{\mu,\theta}, S_0) \rightarrow S_t(G_{\mu,\theta}) = \emptyset \text{ for all } t > 0.
  \]
Model: Agent Based Model (1)

- We apply our theoretical model to large complex networks with 100 agents (Cowan, 2004), assigning random thresholds’ values;

- These networks exhibit high levels of complexity; meaning that it is hard to derive any analytical rule as possible combinations are too large (as for most ABM);

- As carried out in the literature, we use simulations to get our findings (Cowan, 2004; Delre et al., 2006; Akbarpour et al. 2017).
Model : Agent Based Model (2)

- $N=100, n=10$ (eg. Cowan, 2004);

- Each agent is endowed with two thresholds profiles $\mu_i$ and $\theta_i$, drawn independently from a uniform probability distribution with support $[0, 1]$;

- Agents placed on lattice, SW and random graphs according to the WS algorithm;

- At $t_0$, we set the number of initial seeds $S_0 \in [0,..., 100]$, randomly selected, to launch the cascade process. Tests on four learning scenarios $\alpha=[0.1; 0.3; 0.5; 0.7]$;

- 1000 different graphs are created and on each graph a single history is run. The graph is unchanged within a history. We randomized the agents in the seed set and the associated thresholds allocation (Watts, 2002; Lelarge, 2011).
Results & Analysis
Model: Results & Analysis (1) - Agg. Diffusion

Fig. 1. Aggregate diffusion as a function of initial seed sets

\( \alpha = 0.1 \)

<table>
<thead>
<tr>
<th>Lattice</th>
<th>Small World</th>
<th>Random</th>
</tr>
</thead>
</table>

\( \alpha = 0.3 \)

<table>
<thead>
<tr>
<th>Lattice</th>
<th>Small World</th>
<th>Random</th>
</tr>
</thead>
</table>

\( \alpha = 0.5 \)

<table>
<thead>
<tr>
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<th>Small World</th>
<th>Random</th>
</tr>
</thead>
</table>

\( \alpha = 0.7 \)

<table>
<thead>
<tr>
<th>Lattice</th>
<th>Small World</th>
<th>Random</th>
</tr>
</thead>
</table>
Fig. 2. Diffusion heterogeneity measured by variance

\( \alpha = 0.1 \)  
\( \alpha = 0.3 \)  
\( \alpha = 0.5 \)  
\( \alpha = 0.7 \)

Initial seed set

Diffusion variance

Lattice  
Small World  
Random
Model: Results & Analysis (2) - Heterogeneity

One threshold scenario $\theta_i$
Fig. 3. Rate of Cascades convergences as a function of time, $S_0 = [5;35]$
Model: Results & Analysis (4) - Adoption convergence

Fig. 4. (a) Adoption dynamics as a function of time
Discussion: The case of biogas technology

- Barriers: Initial investments cost + knowledge about the technology (Ortiz, 2017).

Our results emphasize the role of underlying networks to alleviate these constraints:

- Favouring systems of exchanges and cooperation: the role of cooperatives (cluster) to diffuse knowledge and invest together (Beaman, 2018);

- Perdersen et al. (2018): More connections to biogas adopters increase the likelihood to adopt the technology (Indonesia).
Conclusions and Takeaways

- Networks: lattice and SW perform better than random networks in terms of diffusion (eg. $S_0=24$, $\alpha=0.7$, Lat = 81%, Rand = 53%); 
  Policy $\rightarrow$ Encouraging connections and exchanges (ie. coop).

- Learning effects: 1) higher diffusion 2) larger aggregate gap - between clustered/random networks (fewer initial agents required). 
  Policy $\rightarrow$ supporting the « good » technology !

- Speed of diffusion: equivalent (random networks converge at slower aggregate adoption level);

- Clustered networks display higher levels of variance for aggregate diffusion level. Policy $\rightarrow$ the case of uncertainty in results ?

- Two thresholds/one threshold frameworks: heterogeneity behaves differently (clustered networks).
Some References


Backup - Networks topologies

- Networks: hierarchical, clustered, sparse, complete...

- Evaluating the influence of network’s structure on diffusion:
  - Low number of nodes: Deriving local analytical rules (eg. Acemoglu et al., 2011; Teytelboym et al., 2016);
  - High number of nodes: Complex systems = numerical approaches (Cowan, 2004; Delre et al., 2006; Singh et al., 2013).

**Watts Strogatz algorithm (1998)**: Matching real world networks, easiness to generate networks (lattice, SW, Random), allows for comparisons through clustering and average path length.
Backup (1) - $\alpha=[0;1]$

1) For $\alpha=0$, the cost function is:

$$C_t = C_0 \times \left(|U_{t=0}^{t-1} S_r|\right)^{-0} = 1$$

whatever the initial seed set. Then, we observe no diffusion in networks at all as the cost remains too high.
Backup (2) - Diffusion gap (baseline Lat.)
Backup (3) - Cascades convergence (1)
Backup (3) - Cascades convergence (2)
Backup (4) - Adoption convergence (1)
Backup (4) - Adoption convergence (2)

\[ S_0 = 25 \]

\[ \alpha = 0.1 \]

\[ \alpha = 0.3 \]

\[ \alpha = 0.5 \]

\[ \alpha = 0.7 \]

\[ S_0 = 35 \]

\[ \alpha = 0.1 \]

\[ \alpha = 0.3 \]

\[ \alpha = 0.5 \]

\[ \alpha = 0.7 \]

Aggregate diffusion (%) vs Time period

Lattice vs Random
Chapter 2

Green Connections: A Network Economics Approach to the Energy Transition
Overview of the Presentation

- Introduction
- Modeling Strategy for Inferring Diffusion Network
- How Environmental Policies Spread? A Network Analysis
- Determinants of Network Formation
- Conclusion
INTRODUCTION
Context (1) - Environmental Policy Needs

- Environmental and climate policies are put forward prominently
  (eg. COP21 Paris Agreement, G7, Youth for Climate).

- Global Warming of 1.5°C - IPCC (2019):
  - Net zero by 2050;
  - « the need of "rapid and far-reaching" transitions in land, energy, industry, buildings, transport, and cities and give policymakers and practitioners the information they need to make decisions that tackle climate change […] ».

- 1,500 environmental laws and policies globally (GRI, 2018).
  - « Since the Kyoto Protocol, increased by a factor of more than 20 » (Climate Change Laws of the World, Special Report, GRI, 2018).
Context (2) - In the United States

- Contribution to Climate change
  - 14% of worldwide GHGs emissions (WRI, 2017), 2nd larger emitter today and first in history (U.N., 2017)!

- COP21 objective: « reducing U.S. emissions to at least 26% under 2005 levels by 2025 » (N.D.C.);

- Trump election (2016): withdrawal from the Paris Agreement; at least 84 environmental rules being rolled back (Harvard Law School, Columbia Law School, 2019);

- Some U.S. states take the political lead against global warming (eg. California, New York; Climate Alliance, 2017).
Federalism, a peculiar environment for policy diffusion:

- States are connected in many ways (e.g., history, culture, the exchange of goods, citizens’ migration, media markets (Desmarais et al., 2015));
- States tend to compete and learn from each other (Berry and Berry, 1990; Pitt, 2010);

Policies regularly spread throughout the American states, driven by underlying forces (i.e., competitive, cooperative, and imitative);

Scholars have mainly investigated the determinants of policy adoption and diffusion (internal, external).
Main factors for Environmental Policy Adoption:

- **Internal**: Citizens ideology (Matisoff, 2008); Partisan control of the state (Huang et al., 2007); liberalism (Matisoff and Edward*, 2014); Environmental organizations membership level (Newmark and Witko, 2007); State's economy (manufacturing & mining) and wealth (*);

- **External**: Geographic proximity (Berry & Berry, 1990, 1992; Mooney & Lee, 1995; Wong & Shen, 2002); Shared characteristics (Volden, 2006); Ideological distance (Chandler, 2009; Grossback, Nicholson-Crotty, & Peterson, 2004).

**Gap in the literature** :

- What about *How Environmental Policies Spread* ?

- And *the specific role of states in the transmission process* ? (key actor)
Main Contributions & Objectives (1)

- **This paper contributes to the literature by:**
  - Being the first to consider a network based approach to environmental policies diffusion/transmission in the U.S. from 1974 onwards;
  - Understanding underlying forces that drives transmission.

- **Objectives are:**
  - Inferring the Environmental Policies Diffusion Network and identifies states facilitating the diffusion and vice versa;
  - Estimating the determinants of the inferred network (ie. those maximizing the transmission likelihood between states).
MODEL & DATA
Inferring the Network: Independent Cascade Model (1)

- Independent Cascade Model to infer a network from series of observations (Gomez-Rodriguez, 2010);

- Weights of the network are interpreted as the rates at which the policy is likely to be transferred between a states-pair;

- These weights summarize effects of latent variables that govern bilateral diffusion and systemic roles of states in the network.
Inferring the Network : Independent Cascade Model (2)

Formally, we are given a series of observations of subsequent types \( (c) \) of environmental policies enacted across US. states where:

- \( c \) is characterized by a cascade of adoptions \( t^c = (t^c_1, ..., t^c_N) \), which is an \( N \)-dimensional vector of observed activation times.

- For each node \( i \), \( t^c_i \) is an element in \( [t^c_0, t^c_0 + T] \cup \{\infty\} \), which is equal to the time at which state \( i \) enacted the legislation \( c \) if finite and is infinite if the state did not enact during a time interval of length \( T \) starting with the first adoption at time \( t^c_0 \).

- The data can then be represented by a set \( c \) of cascades, one cascade for each legislation, and denoted as \( C := \{t^1, ..., t^{|C|}\} \).
Inferring the Network: Independent Cascade Model (3)

- **Objective**: Infer a diffusion network \((G,A)\), where \(G=(V,E)\) and \(A=[\alpha_{j,i}]\) is a matrix of transmission rates, i.e. \(\alpha_{j,i} > 0\) (i.e. quantifies how likely it is that a policy spreads from node \(j\) to node \(i\) if \((j,i) \in E\) (and \(\alpha_{j,i} = 0\) if \((j,i) \notin E\)).

- **ICM**: Infer the maximum likelihood network under the assumption that each cascade is an independent instance of a diffusion process drawn from a parametric model in which the probability of diffusion from node \(j\) to node \(i\) is parameterized by the transmission rate \(\alpha_{j,i}\) that is to be determined.
Inferring the Network : Independent Cascade Model (4)

• Building block of our approach is $f(t_i|t_j; \alpha_{j,i})$, the probability that node $i$ gets activated by node $j$ at time $t_i$, given node $j$ was activated at time $t_j$ and assuming a transmission rate $\alpha_{j,i}$ between nodes $j$ and $i$.

• Given the conditional density $f(t_i|t_j; \alpha_{j,i})$, we can infer the likelihood of a set of cascades $\{t_1, ..., t^{\mathcal{C}}\}$ given a network $A = [\alpha_{j,i}]$ as follows:

First, given a cascade $t^c = (t_1^c, ..., t_N^c)$, the likelihood of node $i$ being activated is:

$$f(t_i|t_1^c, ..., t_N^c \setminus t_i; A) = \sum_{j: t_j \leq t_i} f(t_i|t_j; \alpha_{j,i}) \times \prod_{j \neq k, t_k \leq t_i} S(t_i|t_k; \alpha_{k,i})$$
Inferring the Network: Independent Cascade Model (5)

- One can then compute the likelihood of the activations in a cascade before time $T$:

$$f(t^c \leq T; A) = \prod_{t_i \leq T} \sum_{t_j \leq t_i} f(t_i | t_j; \alpha_{j,i}) \times \prod_{k: t_k < t_i, k \neq j} S(t_i | t_k; \alpha_{k,i})$$

- Further, the likelihood of a cascade accounts for the fact that some nodes did not get activated (we consider that nodes not activated before time $T$ never get activated). It is therefore given by:

$$f(t^c; A) = \prod_{t_i \leq T, t_m > T} \prod_{\alpha_{i,m}} \prod_{t_j \leq t_i} f(t_i | t_j; \alpha_{j,i}) \prod_{k: t_k < t_i, k \neq j} S(t_i | t_k; \alpha_{k,i})$$

- Finally, the likelihood of a set of cascades $C = \{t^1, ..., t^{|C|}\}$, assuming each cascade is independent, is the product of the likelihoods of the individual cascades given by:

$$f(\{t^1, ..., t^{|C|}\}; A) = \prod_{t^c \in C} f(t^c; A)$$
Inferring the Network: Independent Cascade Model (6)

Objective is to find \( A = [\alpha_{j,i}] \) such that the likelihood of the observed set of cascades \( C = \{t^1, \ldots, t^{|C|}\} \) is maximized. We use CVX (MATLAB) - solving convex programs (Grant and Boyd, 2015) and the algorithm NETRATE.

- Structural assumptions about the diffusion process are embedded in the functional form chosen for the function \( f \).

- The probabilistic rate is constant over time (i.e., a Poisson process \( \longrightarrow \) exponential model for the conditional density (Kingman, 1993): \( f(t_i|t_j; \alpha_{j,i}) = \alpha_{j,i} e^{-\alpha_{j,i}} (t_i - t_j), \) (if \( t_j < t_i \) and zero otherwise).
Dataset of Environmental Policies

- 2 types of outputs: adjacency structure of the network; weights.

- Dataset: 74 policies, 51 states, 1974/2018, three initial databases:
  - Database of State Incentives for Renewables & Efficiency (DSIRE);
  - The Center for Climate and Energy Solution (C2ES);
  - US Congress Platform.

<table>
<thead>
<tr>
<th>Scope (Number)</th>
<th>Policies Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Policies (5)</td>
<td>Action Plans and reduction targets</td>
</tr>
<tr>
<td>Climate Change Adaptation (9)</td>
<td>Plans to cope with current climate damages</td>
</tr>
<tr>
<td>Renewable support (24)</td>
<td>Promoting the use of clean energy</td>
</tr>
<tr>
<td>Energy Efficiency (9)</td>
<td>Targeting emissions in the dwelling sector</td>
</tr>
<tr>
<td>Transportation (8)</td>
<td>Promoting the use of clean fuels/vehicles</td>
</tr>
<tr>
<td>Circular Economy (7)</td>
<td>Targeting recycling/products efficient use</td>
</tr>
<tr>
<td>Environmental Concerns (12)</td>
<td>Regulating environment management/health</td>
</tr>
</tbody>
</table>
INFERRED NETWORK & ANALYSIS
Network Analysis : Generalities (1)

Fig. 1. Reconstructed environmental policies diffusion network in the U.S. using geographical layout.
Table 2. General Properties of the Network.

<table>
<thead>
<tr>
<th>Overall Network Characteristics</th>
<th>Exponential Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Nodes</td>
<td>51</td>
</tr>
<tr>
<td>Number of Links</td>
<td>440</td>
</tr>
<tr>
<td>Network Density</td>
<td>0.173</td>
</tr>
<tr>
<td>Mean Degree</td>
<td>8.627</td>
</tr>
<tr>
<td>Mean Path Length</td>
<td>2.075</td>
</tr>
<tr>
<td>Network Diameter</td>
<td>4</td>
</tr>
<tr>
<td>Mean Clustering Coefficient</td>
<td>0.211</td>
</tr>
</tbody>
</table>
Network Analysis: Regions vs. Communities

Table 3. Regional-level statistics.

<table>
<thead>
<tr>
<th>Region</th>
<th>No. of states</th>
<th>Out-degree</th>
<th>In-degree</th>
<th>Source region (%)</th>
<th>Target region (%)</th>
<th>Total degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
<td>9</td>
<td>89</td>
<td>59</td>
<td>20.23</td>
<td>13.41</td>
<td>148</td>
</tr>
<tr>
<td>Midwest</td>
<td>12</td>
<td>98</td>
<td>109</td>
<td>22.27</td>
<td>24.77</td>
<td>207</td>
</tr>
<tr>
<td>West</td>
<td>13</td>
<td>113</td>
<td>130</td>
<td>25.68</td>
<td>29.54</td>
<td>243</td>
</tr>
<tr>
<td>South</td>
<td>17</td>
<td>140</td>
<td>142</td>
<td>31.82</td>
<td>32.27</td>
<td>282</td>
</tr>
</tbody>
</table>

Table 4. Matrix of intra-interregional connections.

<table>
<thead>
<tr>
<th>Region</th>
<th>Northeast</th>
<th>Midwest</th>
<th>West</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
<td>23</td>
<td>14</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td>Midwest</td>
<td>10</td>
<td>30</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>West</td>
<td>11</td>
<td>29</td>
<td>34</td>
<td>39</td>
</tr>
<tr>
<td>South</td>
<td>15</td>
<td>36</td>
<td>43</td>
<td>46</td>
</tr>
</tbody>
</table>

Côme Billard - Ph.D. Candidate - Paris-Dauphine University
Network Analysis: Regions vs. Communities

Fig. 2. Reconstructed network using Force Atlas layout.
Characterization via Degree Distribution

Fig. 3. Cumulative distribution of states’ out-degree and in-degree.

- 70% of nodes have less than 10 out-degrees
- 2% of nodes have more than 17 out-degrees
- Highly connected nodes in the Network
Capturing Leaders / Followers in the Network (1)

- **Centrality measures** (Jackson, 2008):
  - Degree centrality of node $i$: its degree;
  - **The closeness** of node $i$, $1/\Sigma_j d(j,i)$, the average distance of $i$; *(ie. how fast a policy enacted in a state reaches, on average, another state).*
  - **The betweenness** centrality of node $i$: the share of shortest paths in the network on which node $i$ lies *(ie. amount of flows through that state to other states in the network, thus acting as a bridge)*;
  - The eigenvector centrality: a recursive measure that assigns a high value to nodes which are connected to other important nodes.
Capturing Leaders / Followers in the Network (2)

Central States

Less Integrated States

South Dakota
Alaska
District of Columbia
Arizona
Wyoming
West Virginia
North Dakota
Louisiana
Idaho
Delaware
Ohio
Oklahoma
Nebaska
Indiana
Kansas

Minessotta
California
Florida
Massachusetts
Pennsylvania
New York
New Mexico
Wisconsin
Virginia
Rhode Island
New Jersey
Maine
Washington
Missouri
Hawaii

Minessotta
California
Utah
Hawaii
Missouri
Florida
New Jersey
Maine
Wisconsin
Maryland
Louisiana
North Carolina
Idaho
Mississippi
Texas

District of Columbia
South Carolina
Alaska
Rhode Island
Colorado
Washington
South Dakota
North Dakota
Iowa
New Mexico
Pennsylvania
West Virginia
Georgia
Tennessee
Connecticut

0.49
0.51
0.53
0.55
0.57

0
0.133
0.265
0.398
0.53

0
7.5
15
22.5
30

0
75
150
225
300

Closeness

Betweeness

Closeness

Betweeness
THE DETERMINANTS OF TRANSMISSION
Methodology (1)

Given observations of a set of cascades $S = (S_v)_{v \in V}, V$ different policies, we can estimate the determinants of bilateral diffusion by maximum likelihood - i.e. determine the coefficients for which the likelihood of the observed diffusion patterns is maximal.

Panel data about source states $X = (x_{i,t})_{i=1 \cdots N, t=1 \cdots T}$, target states $Y = (y_{j,t})_{j=1 \cdots N, t=1 \cdots T}$, and relationship characteristics $Z = (z_{(i,j),t})_{i=1, \cdots, N, j=1 \cdots N, t=1 \cdots T}$, one can compute the likelihood of a cascade $S_v$ (see. Halleck Vega et al. (2018)).

A natural approach would then be to try to estimate the diffusion probability between country $i$ and $j$ using a logistic model of the form:

$$a_{i,j} = P(\alpha, \beta, \gamma)(x_i, y_j, z_{i,j}): = \frac{1}{1 + e^{-(\alpha \cdot x_i + \beta \cdot y_j + \gamma \cdot z_{(i,j)})}}$$
Methodology (3)

- The default approach (Halleck Vega et al. 2018): compute the likelihood of a set of cascades using the independent cascade model of Gomez Rodriguez et al. (2010). This yields the following equation for the likelihood of the set of observed cascades $S = (S_v)_{v \in V}$:

$$
\mathcal{L}_{\alpha, \beta, \gamma}(S) = \prod_{v \in V} P^{\nu}_{(\alpha, \beta, \gamma)}(X, Y, Z)
$$

- One can then estimate the determinants of diffusion, $(\alpha, \beta, \gamma)$, by maximum likelihood.
Panel Data

- Enrich our dataset with characteristics that can be associated to a state as a source (of the type \( x_i \)), as a target (of the type \( y_j \)), the relationship between pairs of states (of the type \( z_{i,j} \)).
  - Economic and Political characteristics: GDP per capita, population density, citizen ideology, partisan control of state government (Berry et al.’s, 1998; Klarner, 2003; Desmarais et al., 2015), federal government party in charge (eg. Republican/ Democratic);
  - Contiguity (Bromley-Trujillo et al. 2016);
  - Environmental variables: Climate Alliance Membership, Expected economic cost due to global warming (Hsiang et al., 2019), associated amount of CO2 emissions per capita the Genuine Progress Indicator (Fox and Erickson, 2018).
Determinants of Transmission Likelihood

Table on Next Slide
Conclusions and Takeaways (2)

- An epidemic-like model to estimate the network of environmental policies transmission likelihood across American states and evaluate determinants from adoption data. By doing so, we enhance the understanding of environmental policies diffusion and give policy makers insights to maximize the diffusion of green policies.

- Inefficient network organization with key states and vice versa (Minnesota, California, Florida vs. South Dakota, South Carolina, Alaska). Policy → Targeting leaders to maximize diffusion;

- NorthEastern States display highly concentrated diffusion (Regional vs Community approach); Suggests different areas + dynamics of diffusion.
Conclusions and Takeaways (2))

- Contiguity, GPI: key determinants of transmission + Federal gov. color vs. eg. expected climate change economic losses. Policy → Target shared characteristics.
Some References


Policies collected

Adaptation to climate change: Climate Adaptation Plan, Fire prevention policies, General Hazard Plan, Water Plan, Droughts Plan, Droughts Laws (NCLS), Flood Programs, Adaptation plan, Harvesting Water Program;

Renewables support: Wind Energy Support, Interconnection Standards, Electricity Portfolio Standards, Standards for Electricity Power plants, Solar rebate, Water rebate program (solar heating), Energy Efficiency Loan, Solar/Wind access Policy, Public Funds for RES, Performance Based Incentives, Training Program, Sales Tax Incentives, Loan Program, Personal Tax Credit, Property Tax Exemptions, Pace Program, Grant Program, Green Purchasing Power, Hydrogen, Biogas, Solar/Wind Permitting Standards, Mandatory Net Metering, Renewables Portfolio Standard, Corporate Tax Credit);

Circular economy: Water Efficiency, Composting, Beverage Program Nuclear Waste, Stewardship Recycling, Plastic Bag Recycling Policies, Electronic Recycling Program);

Climate Policies: Carbon pricing, GHGs Regulation, Carbon Capture and Storage, GHGs Emissions Targets, US Climate Action Plan);


# Regions

## Description of U.S. Census Bureau - Regions

<table>
<thead>
<tr>
<th>Northeast</th>
<th>Midwest</th>
<th>South</th>
<th>West</th>
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<tbody>
<tr>
<td>Connecticut</td>
<td>Indiana</td>
<td>Delaware</td>
<td>Arizona</td>
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<td>Maine</td>
<td>Illinois</td>
<td>District of Columbia</td>
<td>Colorado</td>
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<td>Massachusetts</td>
<td>Michigan</td>
<td>Florida</td>
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<td>Georgia</td>
<td>New Mexico</td>
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<tr>
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<td>Wisconsin</td>
<td>Maryland</td>
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**Network formation overtime**

**Communities description**

<table>
<thead>
<tr>
<th>1 - Blue</th>
<th>2 - Red</th>
<th>3 - Yellow</th>
<th>4 - Green</th>
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<tbody>
<tr>
<td>Wyoming</td>
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<tr>
<td>Virginia</td>
<td>Vermont</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washington</td>
<td>West Virginia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisconsin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Mexico</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Network formation overtime

72-92

72-2000

72-2008

72-2016
Backup - Leaders Centrality Measures
Backup - Followers Centrality Measures

States

District of Columbia
South Carolina
Alaska
West Virginia
South Dakota
North Dakota
Tennessee
Rhode Island
Colorado
Ohio
Indiana
Illinois
Oklahoma
Georgia
Alabama

Out-degree

District of Columbia
Rhode Island
South Carolina
Colorado
New York
Tennessee
District of Columbia
Massachusetts
New Mexico
Michigan
Oklahoma
Pennsylvania
Iowa
Washington
Alaska
West Virginia

Eigenvector

District of Columbia
Rhode Island
South Carolina
Colorado
New York
Tennessee
District of Columbia
Massachusetts
New Mexico
Michigan
Oklahoma
Pennsylvania
Iowa
Washington
Alaska
West Virginia

In-degree

District of Columbia
Rhode Island
South Carolina
Colorado
New York
Tennessee
District of Columbia
Massachusetts
New Mexico
Michigan
Oklahoma
Pennsylvania
Iowa
Washington
Alaska
West Virginia
Splitting Networks

*Climate and Environmental concerns*
Splitting Networks

Energy

[Diagram of splitting networks with states and connections]
Econometrics Developments
Given observations of a set of cascades $S = (S_v)_{v \in V}, V$ different policies, we can estimate the determinants of bilateral diffusion by maximum likelihood - i.e. determine the coefficients for which the likelihood of the observed diffusion patterns is maximal.

Panel data about source countries $X = (x_{i,t})_{i=1 \cdots N, t=1 \cdots T}$, target countries $Y = (y_{j,t})_{j=1 \cdots N, t=1 \cdots T}$, and relationship characteristics $Z = (z_{(i,j),t})_{i=1 \cdots N, j=1 \cdots N, t=1 \cdots T}$, one can compute the likelihood of a cascade $S_v$ (see. Halleck Vega et al. (2018)).

Given the adoption status in period $t$, the probability for a non-adopting state $j$ to remain non-adopting in period $t+1$ is:

$$\prod_{\{i | S_v(i,t) = 1\}} (1 - P(\alpha, \beta, \gamma)(x_{i,t}^t, y_{j,t}^t, z_{i,j,t}^t))$$

while the probability that it adopts is:

$$1 - \prod_{\{i | S_v(i,t) = 1\}} (1 - P(\alpha, \beta, \gamma)(x_{i,t}^t, y_{j,t}^t, z_{i,j,t}^t))$$
Methodology (2)

Thus the probability of the transition from the adoption vector \( S_v(\cdot, t) \) to the adoption vector \( S_v(\cdot, t + 1) \) is given by:

\[
\prod_{j \mid S_v(j, t+1)=0} \prod_{i \mid S_v(i, t)=1} (1 - P(\alpha, \beta, \gamma)(x_i^t, y_j^t, z_{i,j}^t)) \\
\times \prod_{j \mid S_v(j, t+1)=1} (1 - \prod_{i \mid S_v(i, t)=1} (1 - P(\alpha, \beta, \gamma)(x_i^t, y_j^t, z_{i,j}^t)))
\]

Therefrom, using the assumption that the diffusion process is Markovian, one deduces the likelihood of cascade \( S_v \) as:

\[
\mathcal{P}_{(\alpha, \beta, \gamma)}(X, Y, Z) = \prod_{t=0}^{T-1} \prod_{j \mid S_v(j, t+1)=0} \prod_{i \mid S_v(i, t)=1} (1 - P(\alpha, \beta, \gamma)(x_i^t, y_j^t, z_{i,j}^t)) \\
\times \prod_{t=0}^{T-1} \prod_{j \mid S_v(j, t+1)=1} (1 - \prod_{i \mid S_v(i, t)=1} (1 - P(\alpha, \beta, \gamma)(x_i^t, y_j^t, z_{i,j}^t)))
\]
Chapter 3
Context (1) - Green Deal / Imported Emissions

- Green Deal for Europe (2019):
  - 2030: jump from 40% to 50% GHGs emission reduction objective; Net Zero by 2050.

- Efficient plan if emissions are not outsourced! (i.e. carbon leakage)
  - Resurgent ambition: tackling the issue of imported emissions.
Context (2) - Gap in Emissions

- Disconnection between territorial and consumption based emissions in the E.U.

  2014, United Kingdom (Office of National Statistics, 2019):
  - Territorial emissions = 402 Mt of CO₂
  - Consumption emissions = 656 Mt of CO₂

  2018, France (Haut Conseil pour le Climat, 2020):
  - Territorial emissions = 445 Mt of CO₂
  - Consumption emissions = 749 Mt of CO₂
Context (3) EU Focus - Distribution of industrial imported emissions

Year 2015 : Distribution of imported CO\textsubscript{2} emissions across top industrial sectors : mining (B05-06), coke/refined petroleum products (C19) and basic metals (C24), OECD.
CO₂ emissions embedded in trade, 2017
Share of carbon dioxide (CO₂) emissions embedded in trade, measured as emissions exported or imported as the percentage of domestic production emissions. Positive values (red) represent net importers of CO₂ (i.e. “20%” would mean a country imported emissions equivalent to 20% of its domestic emissions). Negative values (blue) represent net exporters of CO₂.

Source: Peters et al. (2012 updated); Global Carbon Project (2018)
OurWorldinData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY
Main strands of literature - Key insights:

- **Amount of emissions embedded in international trade** (Peters et al., 2011; Kanemoto et al., 2014; Kim et al., 2019; Simola, 2020)

- Russia and China are huge exporters of CO$_2$ emissions: massive exports of energy and carbon intensive final demand goods (Yang, 2012; Boitier, 2012);

- **Legislative design of economic instruments** (Tamioti, 2011; Holzer, 2014; Mehling et al., 2019)
Imported Emissions: Int. Trade, Legislative issues and Economic mechanisms (2)

- **Non-discrimination principle in WTO law** (equal treatment of trading partner (Art. I GATT) **but**
  Exemptions possible under specific circumstances (e.g. Art XX (b) GATT: *measures « necessary » to protect human, animal and plant life or health*);

- BCAs should avoid differentiating between trade partners based on country-specific characteristics (such as policies) & account for their climate efforts;

- BCAs should demonstrate a sufficient environmental nexus;

- BCAs to exempt exports & BCAs coupled with free allocation are legally riskier.
Imported Emissions: Int. Trade, Legislative issues and Economic mechanisms (3)

- Economic instruments/impacts (Monjon and Quirion, 2011; Droge et al., 2019)

- BCA mechanisms reduce carbon leakage (Böhringer et al., 2012; Fischer and Fox, 2012);

- Import-BCA = dynamic incentives for stronger carbon pricing in other regions (to capture the additional tax revenue) (Helm, Hepburn and Ruta, 2012);

- Zachmann and McWilliams (2020) : EU analysis - Unclear effects on carbon leakage + potential negative impacts (trading partners).
Imported Emissions: Int. Trade, Legislative issues and Economic mechanisms (3)

- Energy intensive sectors (e.g. cement and steel) and carbon pricing: **Limited impacts on both competitiveness & carbon leakage** (Martin, Muûls and Wagner, 2016; Dechezleprêtre and Sato, 2017; Dechezleprêtre et al., 2020);

- BCAs difficult to implement (WTO) + effectiveness largely driven by the design of the instrument (e.g. carbon content measurement, tariffs).
Systemic perspective: How could we capture intensity of demand/supply of imported products? of Imported Emissions?

Source: Godin et al. (2019).
Missing answers?

- What about the *dynamics of demand and supply of dirty imports* within an economy?
- And *the specific role of economic sectors in reducing such patterns*?

Objectives/Contributions are:

- Identify the sector most likely to create imported emission reductions/provide an estimation of potential amounts of emissions that could be reduced (i.e. *interactions across sectors*);
Missing answers (2) and Data

- Study emission reduction cascades down from top industrial sectors to the rest of the economy;

- Provide an short-term estimate of the impact of a carbon-related tax on imported emissions from basic metals sectors;

  - France, Germany, Italy, Poland, United Kingdom;

Green Connections: A Network Economics Approach to the Energy Transition
Methodology for

Emission Reduction Coefficients

and Cascades of Emissions
**Approach (1) : Input Output Tables**

*Figure 1. A stylized Input-Output Table (Cahen-Fourot et al., 2019).*

<table>
<thead>
<tr>
<th></th>
<th>Intermediate uses</th>
<th>Final uses (f)</th>
<th>Total use (TU)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Production</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sector A</td>
<td>Products of A used as inputs by A</td>
<td>Final use of products by A</td>
<td>Total use of products of A</td>
</tr>
<tr>
<td>Sector B</td>
<td>Products of B used as inputs by B</td>
<td>Final use of products by B</td>
<td>Total use of products of B</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>Total intermediate inputs</td>
<td>Total final uses</td>
<td>Total uses</td>
</tr>
</tbody>
</table>

**Value added (v)**
- Comp. of employees
- Cons. of fixed capital
- Operating surplus
- Total value added

**Output**
- Total domestic output

**Imports**
- Total imports

**Total supply (TS)**
- Total supply

*Green Connections: A Network Economics Approach to the Energy Transition*
Approach (1) : From IOTs to Imports

- Measuring use of imports in IOTs is a hard task! (e.g. granularity of data);

- Input similarity : Proxy measurement form of imports sub-allocation

  Within product categories of input-output tables, mixes of imports and country-made products are the same and therefore have the same destinations (U.S. National Research Council of the National Academies (2006));

- If mining imports 90% of its total supply, we assume this amount to be uniformly distributed across downstream sectors.
Approach (2) : Ghosh Model Output

- \( B = \hat{x}^{-1}Z \), Matrix of output allocation coefficients;

  - Each element \( b_{i,j} \) quantifies the share of industry \( i' \)'s output that is used by industry \( j \).

- **Ghosh Matrix defined as :** \( G = (I-B)^{-1} \)

  - Each \( g_{i,j} \) of \( G^T \): the change in output \( x \) in sector \( i \) that would result from a unitary change of primary inputs flowing into sector \( j \) —> *Captures short-term effects!*

  - A decrease of one monetary unit of primary inputs contributing to production in sector \( i \) will decrease the output of sector \( j \) by an amount equals to \( g_{i,j} \).
Approach (3) : Emission Reduction Coef.

- We define $E_i = e_i / M^d_i$ as the imported emission intensity of sector $i$, where $M^d$ represents the domestic output of the sector.

- Multiplying the diagonalised form of the vector of emission intensities by the Ghosh matrix, we find the matrix $S$ of emission reduction coefficients: $S = \hat{E}G^T$

- Now, elements $s_{i,j}$ of matrix $S$ : the change in imported emissions in sector $i$ generated by a unitary change of primary inputs ($\$M$) used by sector $j$. 
Approach (4) : From Emission Reduction Coef. to Networks of Emission Cascades

- We can treat the S matrix as an adjacency matrix to a directed network:
  
  - We select top activities (those exhibiting largest total $s_{i,j}$) to be the origin of the cascading contraction of emissions;
  
  - We identify sectors affected by top $q$ percentile of outward edges and place them on the first layer;
  
  - We repeat the procedure to the sectors in the first/second/... and so on to capture the diffusion of emission contraction within the whole industrial system.
## Approach (3): Productive sectors

Table 3. Breakdown of examined NACE Sectors.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Code</th>
<th>Sector description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Agriculture, forestry and fishing</td>
</tr>
<tr>
<td>B05-06</td>
<td>2</td>
<td>Mining and extraction of energy producing products</td>
</tr>
<tr>
<td>B07-08</td>
<td>3</td>
<td>Mining and quarrying of non-energy producing products</td>
</tr>
<tr>
<td>B09</td>
<td>4</td>
<td>Mining support service activities</td>
</tr>
<tr>
<td>C10-12</td>
<td>5</td>
<td>Food products, beverages and tobacco</td>
</tr>
<tr>
<td>C13-15</td>
<td>6</td>
<td>Textiles, wearing apparel, leather and related products</td>
</tr>
<tr>
<td>C16</td>
<td>7</td>
<td>Wood and of products of wood and cork (except furniture)</td>
</tr>
<tr>
<td>C17-18</td>
<td>8</td>
<td>Paper products and printing</td>
</tr>
<tr>
<td>C19</td>
<td>9</td>
<td>Coke and refined petroleum products</td>
</tr>
<tr>
<td>C20-21</td>
<td>10</td>
<td>Chemicals and pharmaceutical products</td>
</tr>
<tr>
<td>C22</td>
<td>11</td>
<td>Rubber and plastics products</td>
</tr>
<tr>
<td>C23</td>
<td>12</td>
<td>Other non-metallic mineral products</td>
</tr>
<tr>
<td>C24</td>
<td>13</td>
<td>Manufacture of basic metals</td>
</tr>
<tr>
<td>C25</td>
<td>14</td>
<td>Fabricated metal products, except machinery and equipment</td>
</tr>
<tr>
<td>C26</td>
<td>15</td>
<td>Computer, electronic and optical products</td>
</tr>
<tr>
<td>C27</td>
<td>16</td>
<td>Electrical equipment</td>
</tr>
<tr>
<td>C28</td>
<td>17</td>
<td>Machinery and equipment n.e.c.</td>
</tr>
<tr>
<td>C29</td>
<td>18</td>
<td>Motor vehicles, trailers and semi-trailers</td>
</tr>
<tr>
<td>C30</td>
<td>19</td>
<td>Other transport equipment</td>
</tr>
<tr>
<td>C31-33</td>
<td>20</td>
<td>Other manufacturing, repair and installation of machinery and equipment</td>
</tr>
<tr>
<td>D-E</td>
<td>21</td>
<td>Electricity, gas, water supply, sewerage, waste and remediation services</td>
</tr>
<tr>
<td>F</td>
<td>22</td>
<td>Construction</td>
</tr>
</tbody>
</table>
Emission Reduction Coefficients
## Emission Reduction Coefficients

<table>
<thead>
<tr>
<th>France</th>
<th>Germany</th>
<th>Italy</th>
<th>Poland</th>
<th>U.K.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining A (0.0689)</td>
<td>Mining A (0.0089)</td>
<td>Mining B (0.0081)</td>
<td>Mining A (0.0012)</td>
<td>Mining A (0.0004)</td>
</tr>
<tr>
<td>Mining C (0.0034)</td>
<td>Mining B (0.0018)</td>
<td>Mining A (0.0024)</td>
<td>Basic metals (0.0005)</td>
<td>Mining B (0.0004)</td>
</tr>
<tr>
<td>Mining B (0.0002)</td>
<td>Mining C (0.0008)</td>
<td>Mining C (0.0008)</td>
<td>Mining B (0.0004)</td>
<td>Basic metals (0.0003)</td>
</tr>
<tr>
<td>Basic metals (0.0001)</td>
<td>Basic metals (0.0001)</td>
<td>Basic metals (0.0002)</td>
<td>Chemicals (0.0003)</td>
<td>Electrical eq. (0.0003)</td>
</tr>
<tr>
<td>Electrical eq. (0.0001)</td>
<td>Coke-refined petrol. (0.0001)</td>
<td>Chemicals (0.0001)</td>
<td>Machinery &amp; eq. (0.0003)</td>
<td>Computer-electronics (0.0002)</td>
</tr>
</tbody>
</table>

### Exposure to Emission Reduction Multipliers (3)

| Coke & refined petrol. (0.0420) | Coke & refined petrol. (0.0053) | Basic metals (0.0068) | Basic metals (0.0009) | Other manufacturing (0.0004) |
| Electricity & gas (0.0222) | Basic metals (0.0026) | Coke-refined petrol. (0.0010) | Electricity-gas (0.0006) | Basic metals (0.0004) |
| Chemicals (0.0027) | Chemicals (0.0011) | Mining A (0.0009) | Electrical eq. (0.0003) | Coke-refined petrol. (0.0003) |
| Construct. (0.0026) | Electricity & gas (0.0009) | Chemicals (0.0008) | Machinery-eq. (0.0003) | Other transport eq. (0.0002) |
| Basic metals (0.0011) | Mining A (0.0007) | Other non-met. min. (0.0007) | Coke-refined petrol. (0.0003) | Electrical eq. (0.0002) |

**“Raw results” - a drop in imported emissions within the whole industrial system generated by a unitary decrease of primary inputs ($M$) used by sector $j$.**

*Green Connections : A Network Economics Approach to the Energy Transition*
Cascades (e.g. France and Germany)

France

Germany

Green Connections: A Network Economics Approach to the Energy Transition
Different pathways - largest immediate emission reduction:

- **Coke and Refined Petroleum Products (C19)** (France, Germany, Poland, U.K.);
- **Chemicals and Pharmaceutical Products (C20-21)** (France, Germany, U.K.);
- **Basic metals (C24)** - well connected! (Germany, Italy, Poland);
- **Electricity and Gas (D-E)** (France, Germany, Poland, U.K.)

From coke, the reduction cascades often continue affecting:

- Basic metals, other non metallic mineral products, chemicals and pharmaceutical products
Propagation: Takeaways (2)

- From chemicals the reduction cascades often continues affecting:
  - Plastics and rubber products, textiles

- From basic metals the reduction cascades often continues affecting:
  - Fabricated metal products, machinery and equipment, electrical equipment, motor vehicles and other transport equipment

- From elec/gas the reduction cascades often continues affecting:
  - Other non-metallic mineral products and chemicals and pharmaceutical products
Taxing Basic Metals Imports
We investigate the potential short-term impacts of a $25 carbon price on imported emissions from basic metals across sectors (a proxy measurement).

Bar chart 6. % increase cost of sectoral domestic imported inputs, top sectors.
Conclusion

- Mining displays the highest emission reduction coefficients;

- We can identify particularly relevant cascade patterns - but differences across E.U. countries!

- Transition away from fossil fuel likely to have a systemic impacts on imports consumed as inputs —> Greening exposed industrial processes;

- Basic Metals is a huge supplier for other industrial sectors (e.g. Germany);

- Taxing imported carbon from basic metals —> heavy impacts on fabricated metal products / disparities across countries — > compensation/exposure?
Appendices
Appendix (1) - Imported Emissions by products

*Distribution of imported CO$_2$ emissions across mining (B05-06), coke/refined petroleum products (C19) and basic metals (C24)*
Appendix (2) - NACE Sectors

*Table 2. NACE Sectors*

<table>
<thead>
<tr>
<th>Sector code</th>
<th>Sector description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Agriculture, forestry and fishing</td>
</tr>
<tr>
<td>B</td>
<td>Mining and Quarrying</td>
</tr>
<tr>
<td>C</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>D</td>
<td>Electricity, gas, steam and air conditioning</td>
</tr>
<tr>
<td>E</td>
<td>Water supply; sewerage; waste management and remediation services</td>
</tr>
<tr>
<td>F</td>
<td>Constructions and construction works</td>
</tr>
<tr>
<td>G</td>
<td>Wholesale retail trade; repair of motor vehicles and motorcycles</td>
</tr>
<tr>
<td>H</td>
<td>Transportation and storage</td>
</tr>
<tr>
<td>I</td>
<td>Accommodation and food services activities</td>
</tr>
<tr>
<td>J</td>
<td>Information and communication</td>
</tr>
<tr>
<td>K</td>
<td>Financial and insurance activities</td>
</tr>
<tr>
<td>L</td>
<td>Real estate activities</td>
</tr>
<tr>
<td>M</td>
<td>Professional, scientific and technical activities</td>
</tr>
<tr>
<td>N</td>
<td>Administrative and support service activities</td>
</tr>
<tr>
<td>O</td>
<td>Public administration and defence: compulsory social security</td>
</tr>
<tr>
<td>P</td>
<td>Education</td>
</tr>
<tr>
<td>Q</td>
<td>Human health and social work activities</td>
</tr>
<tr>
<td>R</td>
<td>Arts, entertainment and recreation</td>
</tr>
<tr>
<td>S</td>
<td>Other services activities</td>
</tr>
<tr>
<td>Sector</td>
<td>France</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Agriculture, forestry and fishing</td>
<td>3,4</td>
</tr>
<tr>
<td>Mining and extraction of energy producing products</td>
<td>19,5</td>
</tr>
<tr>
<td>Mining and quarrying of non-energy produc-</td>
<td>1,1</td>
</tr>
<tr>
<td>ting products</td>
<td></td>
</tr>
<tr>
<td>Mining support service activities</td>
<td>0,3</td>
</tr>
<tr>
<td>Food products, beverages and tobacco</td>
<td>7,8</td>
</tr>
<tr>
<td>Textiles, wearing apparel, leather and relat-</td>
<td>9,6</td>
</tr>
<tr>
<td>ed products</td>
<td></td>
</tr>
<tr>
<td>Wood and of products of wood and cork (ex-</td>
<td>1,1</td>
</tr>
<tr>
<td>cept furniture)</td>
<td></td>
</tr>
<tr>
<td>Paper products and printing</td>
<td>2,9</td>
</tr>
<tr>
<td>Coke and refined petroleum products</td>
<td>14,1</td>
</tr>
<tr>
<td>Chemicals and pharmaceutical products</td>
<td>19,8</td>
</tr>
<tr>
<td>Rubber and plastics products</td>
<td>8,7</td>
</tr>
<tr>
<td>Other non-metallic mineral products</td>
<td>7</td>
</tr>
<tr>
<td>Manufacture of basic metals</td>
<td>18,6</td>
</tr>
<tr>
<td>Fabricated metal products, except machinery</td>
<td>7</td>
</tr>
<tr>
<td>and equipment</td>
<td></td>
</tr>
<tr>
<td>Computer, electronic and optical products</td>
<td>12,6</td>
</tr>
<tr>
<td>Electrical equipment</td>
<td>12,8</td>
</tr>
<tr>
<td>Machinery and equipment n.e.c.</td>
<td>12,1</td>
</tr>
<tr>
<td>Motor vehicles, trailers and semi-trailers</td>
<td>11,2</td>
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<tr>
<td>Other transport equipment</td>
<td>10,8</td>
</tr>
<tr>
<td>Other manufacturing; repair and installation of machinery and equipment</td>
<td>11,6</td>
</tr>
<tr>
<td>Electricity, gas, water supply, sewerage, waste and remediation services</td>
<td>3,3</td>
</tr>
<tr>
<td>Construction</td>
<td>0,3</td>
</tr>
</tbody>
</table>
Table 4. b. CO₂ emissions in gross imports, year 2015.

<table>
<thead>
<tr>
<th>Country</th>
<th>CO₂ emissions (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>195 600</td>
</tr>
<tr>
<td>Germany</td>
<td>318 900</td>
</tr>
<tr>
<td>Italy</td>
<td>177 000</td>
</tr>
<tr>
<td>Poland</td>
<td>78 000</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>217 900</td>
</tr>
</tbody>
</table>
Cascades: Italy and Poland

Italy

Poland

Green Connections: A Network Economics Approach to the Energy Transition
Cascades : United Kingdom

United Kingdom

Green Connections : A Network Economics Approach to the Energy Transition
<table>
<thead>
<tr>
<th>Code</th>
<th>Code</th>
<th>Description</th>
<th>French Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>051</td>
<td>05</td>
<td>Hard coal</td>
<td>Houille</td>
</tr>
<tr>
<td>052</td>
<td>05</td>
<td>Lignite</td>
<td>Lignite</td>
</tr>
<tr>
<td>061</td>
<td>06</td>
<td>Crude petroleum</td>
<td>Pétrole brut</td>
</tr>
<tr>
<td>062</td>
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<td>Gaz naturel, liquéfié ou gazeux</td>
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<td>08</td>
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<td>Pierres, sables et argiles</td>
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<td>Services de soutien à l'extraction d'hydrocarbures</td>
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<td>Support services to other mining and quarrying</td>
<td>Services de soutien aux autres industries extractives</td>
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<td>Processed and preserved fish, crustaceans and molluscs</td>
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<td>Chaussures</td>
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<td>Wood, sawn and planed</td>
<td>Bois, sciés et rabotés</td>
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<td>Products of wood, cork, straw and plaiting materials</td>
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<td>18</td>
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<td>Reproduction d'enregistrements</td>
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<td>Pesticides et autres produits agrochimiques</td>
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<td>Savons, produits d'entretien et parfums</td>
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<td>Fibres artificielles ou synthétiques</td>
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<td>Produits pharmaceutiques de base</td>
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<td>Produits en caoutchouc</td>
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<td>Produits en plastique</td>
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<td>Glass and glass products</td>
<td>Verre et articles en verre</td>
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<td>Cement, lime and plaster</td>
<td>Ciment, chaux et plâtre</td>
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<td>23</td>
<td>Articles of concrete, cement and plaster</td>
<td>Ouvrages en béton, en ciment ou en plâtre</td>
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<td>Cut, shaped and finished stone</td>
<td>Pierre taillée, façonnée et finie</td>
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<td>Other non-metallic mineral products</td>
<td>Autres produits minéraux non métalliques</td>
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<td>Produits sidérurgiques de base et ferroalliages</td>
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<td>Tubes, pipes, hollow profiles and related fittings, of steel</td>
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<td>Weapons and ammunition</td>
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<td>Équipements de communication</td>
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<td>Produits électroniques grand public</td>
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<td>Measuring, testing and navigating equipment; watches</td>
<td>Instruments et appareils de mesure, d'essai et de navigation</td>
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<td>Irradiation, electromedical and electrotherapeutic equipment</td>
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<td>Optical instruments and photographic equipment</td>
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<td>Magnetic and optical media</td>
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<td>Electric motors and generators, Transformers and electric controls, transformers, and</td>
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<td>Véhicules automobiles</td>
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<td>Carrosseries automobiles; remorques et semi-remorques</td>
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<td>Equipements automobiles</td>
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<td>Instruments de musique</td>
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<td>Articles de sport</td>
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<td>Jeux et jouets</td>
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<td>Instruments et fournitures à usage médical et dentaire</td>
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<td>Installation de machines et d'équipements industriels</td>
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<td>Gaz manufacturé; distribution de combustibles gazeux par conduites</td>
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<td>Eau naturelle; traitement et distribution d'eau</td>
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<td>Collecte et traitement des eaux usées; boxe d'épuration</td>
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<td>Déchets; collecte des déchets</td>
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<td>Ouvrages et travaux de construction relatifs aux réseaux</td>
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<td>Travaux de démolition et de préparation de sites</td>
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<td>Building completion and finishing works</td>
<td>Travaux de finition</td>
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<td>Other specialised construction works</td>
<td>Autres travaux de construction spécialisés</td>
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Germany reluctant to BTA

BERLIN (Reuters) - Germany's powerful BDI industry association on Wednesday criticized a Franco-German proposal to consider a European carbon border tax to protect firms investing in green technology from emission-intensive competition abroad.

The industry group has close links to German Chancellor Angela Merkel’s center-right conservatives and has the power to torpedo efforts to introduce a European-wide carbon adjustment tax through aggressive lobbying in Brussels and Berlin.

France and Germany last week issued a joint statement in which both countries said that the introduction of such a levy should be an option in European efforts to fight climate change.

It was the first time Germany has shown a willingness to consider a carbon border tax, pushed for by French President Emmanuel Macron, despite concerns that such a move could increase trade tensions with the United States.

Speaking to reporters in Berlin on Wednesday, BDI President Dieter Kempf said implementing a carbon adjustment tax for imports from countries with less rigorous climate protection schemes was technically difficult, especially for sectors with a high degree of cross-border division of labor.

Kempf also warned that such a levy could trigger retaliatory trade measures from other countries which could hit Germany's export-dependent, open economy particularly hard.
Chapter 4
Figure 4.2: Distribution of total GHG emissions (CO₂ eq.) across Agriculture (A), Electricity and Gas (D-E) and Other Non-metallic mineral products (C23).
Figures 3 a, b, c, d, e: Hierarchical networks of emission cascades across economic sectors in France, Germany, Italy, Poland and Spain.

a, b, France (left) and Germany (right)
c,d, Italy (left) and Poland (right)
e, Spain
4: COVID-19 Recovery Packages and Industrial Emission Rebounds: Mind the Gap

Strongest immediate emission reductions:

- From mining to energy intensive manufacturing sectors (coke and petroleum products, steel, iron, chemicals) and power generation (e.g. electricity & gas), further affecting industrial sub-sectors (e.g. construction, rubber and plastics products).

- Common characteristics across countries = opportunity to design recovery packages sharing common patterns! (aiming at limiting emission rebounds in sectors identified (e.g. mining (B), coke and refined petroleum products (C19), chemicals (C20-21) and electricity and gas (D-E)).