# Green zones: from theory to practice

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# Preliminary considerations

- In Europe, we live with Covid-19 since February 2020.
- In France, there have been 4 waves, and now we are in the 5th.
- A common goal has emerged: reduce the impact of Covid-19 on health, the economy, & liberties
- To achieve it, a large variety of tools and measures have been implemented:
  - Public health measures (mask wearing, social distancing, ventilation)
  - Mobility restrictions (within a region, interregional, international)
  - Closures (schools, leisure, restaurants)
  - Limit interactions (their size, their nature, curfews)
  - Lockdowns (national, targeted)
  - Vaccination (prioritization, mandates, acceleration)
  - Covid certificates (to travel, to take part in gatherings)
- A small group of scientists is progressively formed (math, econ, sociology, health, politics)

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- Some of our proposals are adopted (to some extent), others are not.

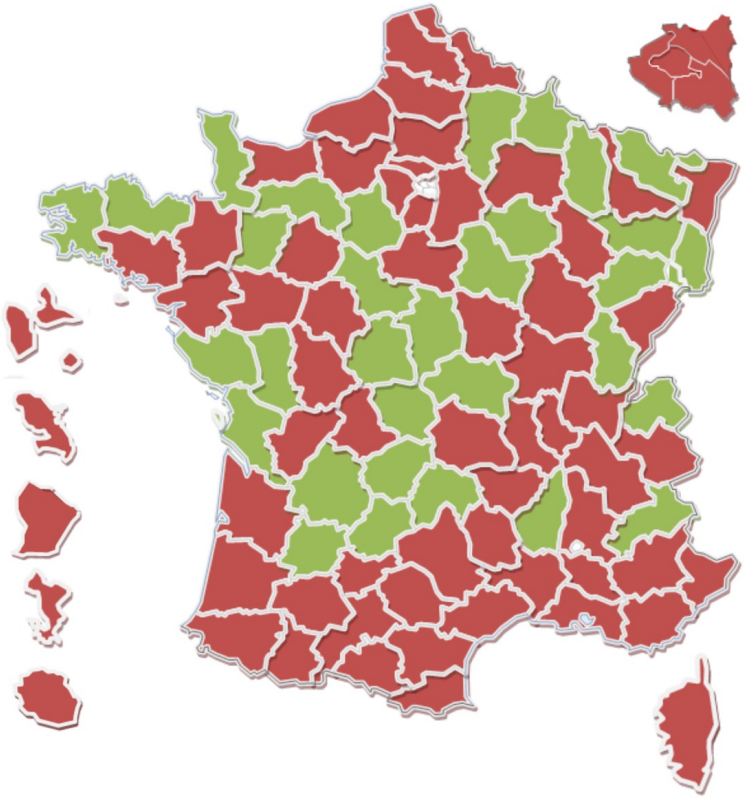
# Three policy recommendations we made

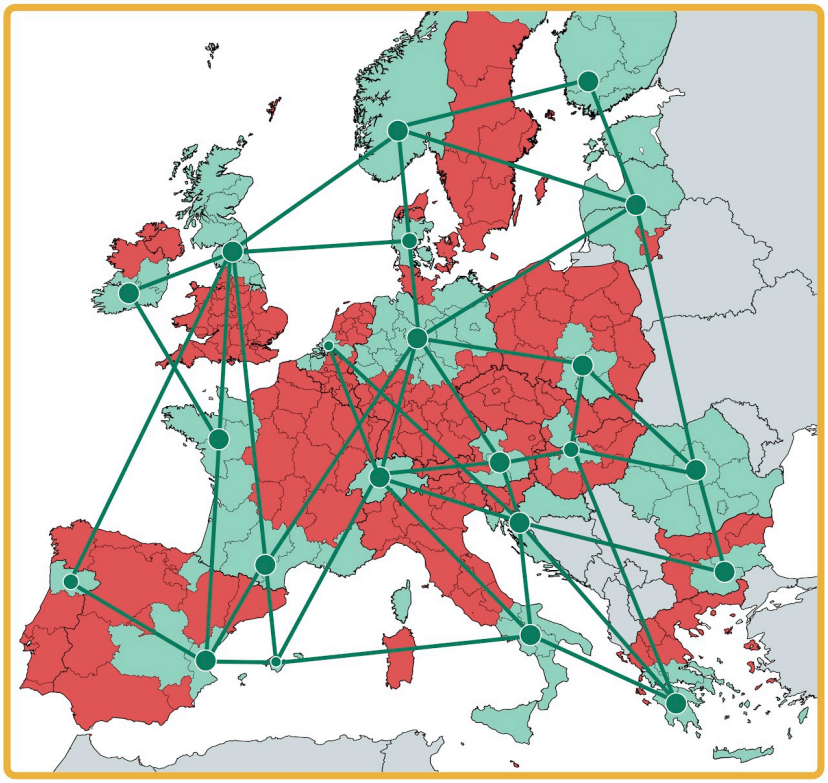
1. Green zoning (control the spread & minimize social and economic damage) April + May 2020
   - **a)** Divide the country, or continent, into green or red zones of a manageable size dependent on common objective criteria determined by Health Authorities.
   - **c)** Adopt colour-dependent public health measures: in particular, return to normal in green zones.
   - **d)** Protect green zones : allow free travel between them, but limit other travel as much as possible.

2. Vaccination priority (control the spread & protect the population more efficiently) October 2020
   - **a)** Prioritise dependent on probability of contracting a severe form of Covid, i.e. this depends on exposure and vulnerability. (conditional on catching it, probability of having a severe form), i.e. (1) place of residence, (2) profession and (3) age.
   - **b)** Exposure (prob. of catching Covid) depends on (1)-(3), i.e. green & red, connexionnists, and travellers, while vulnerability (prob. of a severe form, conditional on having Covid) depends mainly on (3).
   - **d)** In addition, red zones should be given more doses per capita, as the risk of severe forms is higher

3. Covid certificates (spur vaccine uptake & avoid closures and lockdowns) March + May 2021 + ongoing
   - **a)** Include three criteria (test, antibodies, vaccines) to avoid social unrest.
   - **b)** Adopt Covid certificates to reopen high-risk places (when they were closed)
   - **c)** Extend Covid certificates to high- and middle-risk places if vaccine uptake stalls & comes a new wave of infection.
   - d) Integrate boosters in the Covid certificate by making it time-dependent, i.e. expire X months after 2$^{nd}$ dose.

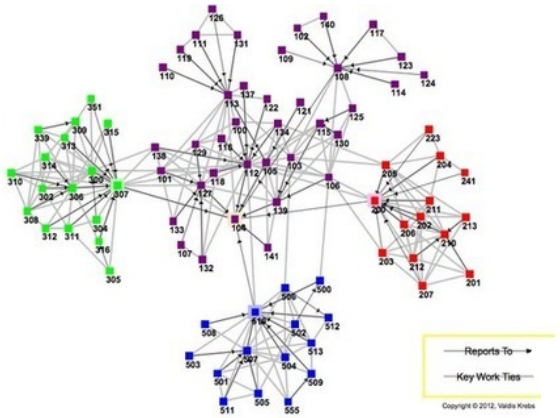
# Green zones

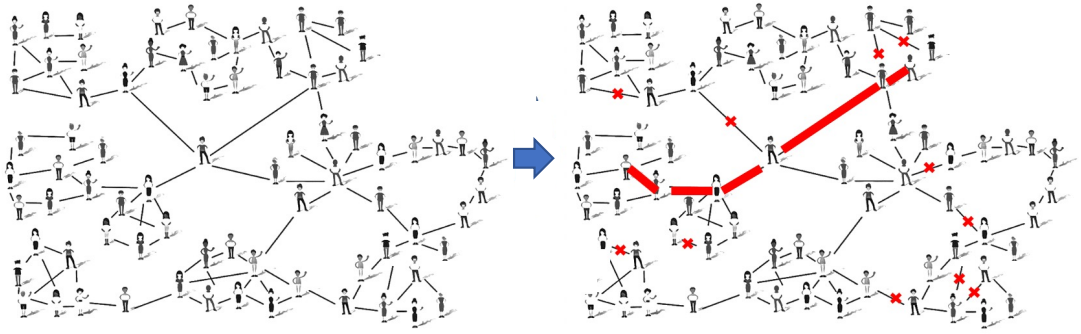




# Green zones: theoretical model

The virus spreads using a *physical proximity network,* that is a wieghted graph with two features:
**a)** spatial scale structure (centrality, density) **b)** small world property (or 6 degree of separation)



Non-pharmaceutical intervention (NPIs) act on this network in two manners:

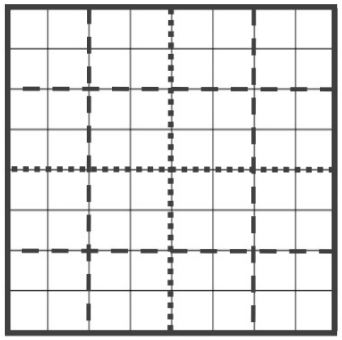
- Reducing the intensity of the existing links : hygiene measures, masks wearing, social distancing
  → NPIs slow down the transmission (but the small world property remains)
- Deleting some links : lockdowns, curfews, limit gatherings, travel restrictions, closures
  → Targeted travel restrictions allow to cut the graph efficiently in disjoint pieces

Remark: Different approach from SIR models

# Model

- Pre-define a partition of the country with different “levels” (e.g. municipalities, provinces, regions,  country). Smallest zones are cells.
- Initially, each cell is either green or red depending on their status.
- Red cell: the virus is out of control, so stricter measures.
- Green cell: virus under control, progressive return to normal.

- Partitionning can be done in various ways, for instance, for Ile-de-France:



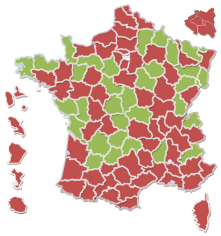
- For simplicity, take a square and divide “dychotomically”

(e.g. power of two, in the example $2^3$ times $2^3$ like chessboard)

# Dynamic

- At time t=0 a fraction $p_0 > 0$ of cells is set red (i.i.d.).
- At each time t = 1, 2,3 . . . every cell can become, or re-become, red, in which we attribute it an integer X~U(a,b), i.e. number of days before turning green (recovery time)
- For each cell, this probability is given by $p(t) = q_{exo}\, r(t)$, where $q_{exo}$ is a parameter and r(t) is the proportion of red cells at time t, and again, i.i.d.
- On the other hand, when neighbouring cells remain green for a certain time, they are merged into a bigger green zone. Similarly, green zones can be aggregated into bigger zones, and so on.
- When a cell becomes red inside a green zone, every cell within the zone also becomes red at a probability depending on the distance to the hotspot c via another parameter $q_{endo}$, i.e. with probability $q_{endo}^{\,d(c,c')}$ for every c' in the zone.

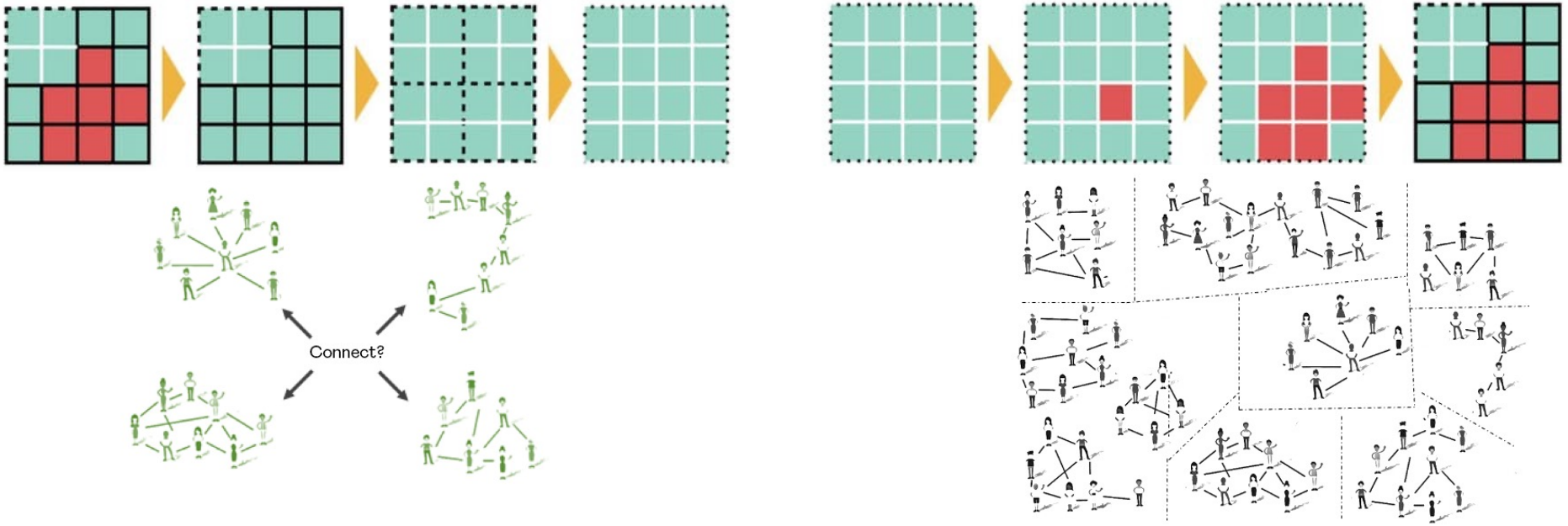
# Green zones in practice: the French case



Simplify as much as possible the model & collaborate with others (health & econ & politics)

- Choose ‘zones’ that are socially and politically acceptable, and economically relevant (Conseil d’Analyse Economique)
- Choose epidemiological criteria that are available and relevant (Conseil scientifique + Haute Autorité de Santé)

Relaxing travel restrictions where Covid is controlled ⟷ Zoning back in case of a resurgence



March 2021

# Use simulations for qualitative validation and visualization

**Model**

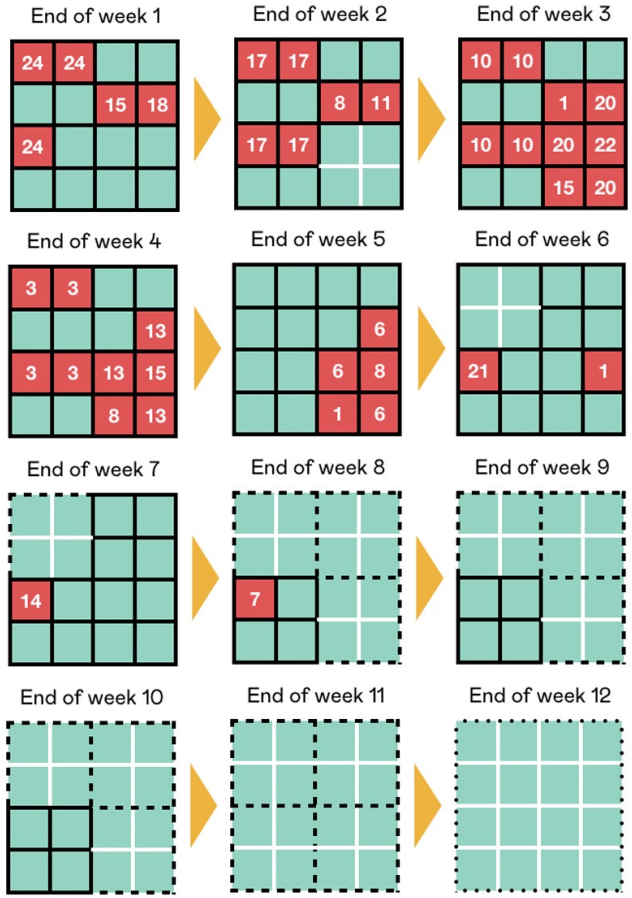
Simple 'chessboard-type' model* with three parameters:

- Exogenous contamination rate: probability that a cell becomes red, dependent on the total number of red cells)
- Endogenous contamination rare: probability that a cell becomes red when another cells from the same zone becomes red).
- Lockdown duration: when a cell newly becomes red, it goes into lockdown a random number of days

* Inspired by the segregation model of Schelling

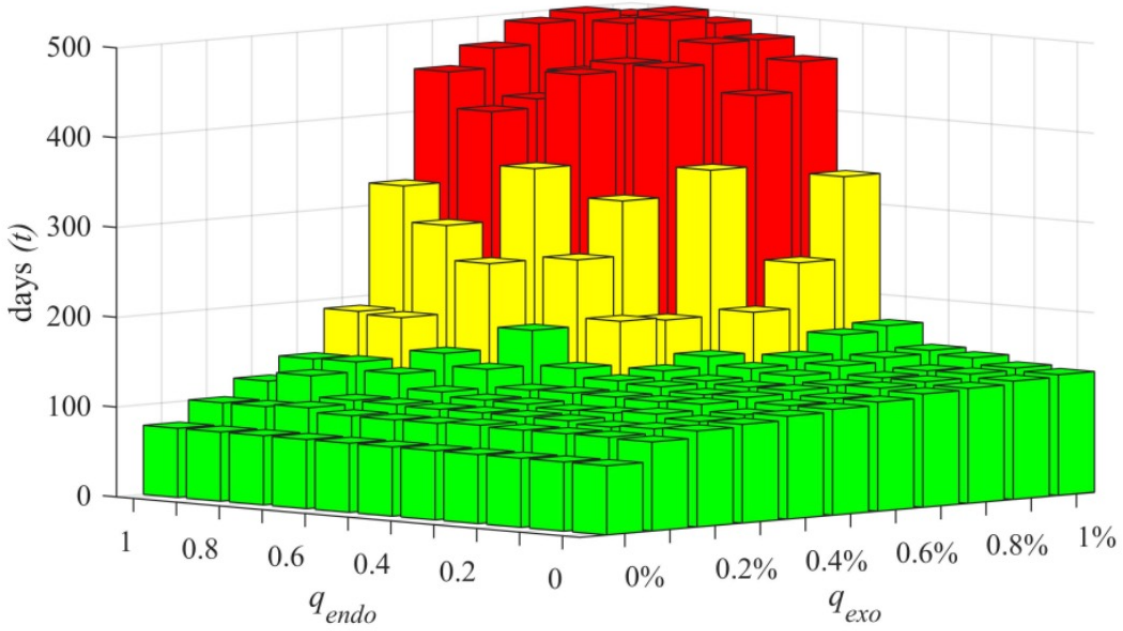
**Results**

- Green zones grow rapidly provided that contamination rates remain controlled. Otherwise, green & red alternate forever.
- The model is robust to perturbations.
- For countries like France & Spain: entirely green in 2-3 months




Simulation with $p_0$=0.3, $q_{exo}$ = 0.05, $q_{endo}$ = 1, and X~U[14,28]

Figure 8: *Simulation for* $(a, b) = (14, 28)$. *Figure truncated at 500 days.*



# Qualitative results

- We run simulation for X ~ U(a,b) for different values of a and b
- A common phase transition phenomenon is observed in both dimensions, $q_{endo}$ and $q_{exo}$.
- By comparing all these figures, we note that the phase transition does not seem to be strongly affected by the interval of recovery (a, b).
- To achieve full control over the virus in reasonable time (i.e. all zones are green and reunited within 4 month, it is necessary to maintain $q_{endo}$ and $q_{exo}$ below certain thresholds (here ≤ 50% and ≤ 0.5%)

These results highlight the importance of keeping public measures in place (to maintain $q_{endo}$ small) and travel restrictions (to maintain $q_{exo}$) small to exit the pandemic within an acceptable time-frame.

Otherwise, our simulation suggests that the spread would not be contained until other measures, such as vaccination, are available.

# Advantages of green zoning

- Break chains of transmission and desynchronize
- Minimize societal & economic damage by progressively returning to normal
- Easily combined with other measures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OLIU-BARTON: CONECTAR REGIONES LIBRES DE COVID-19 PODRÍA SALVAR MILLONES DE EMPLEOS
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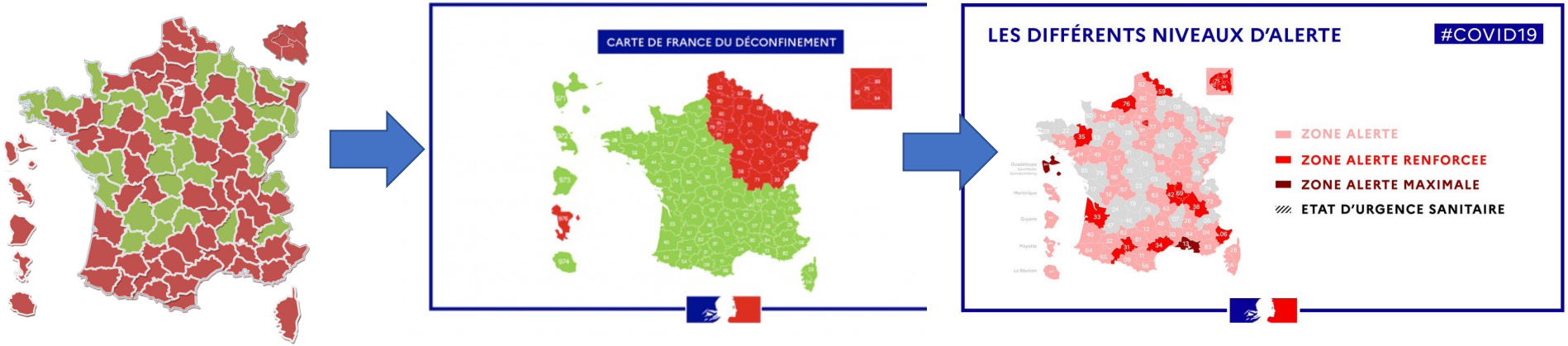
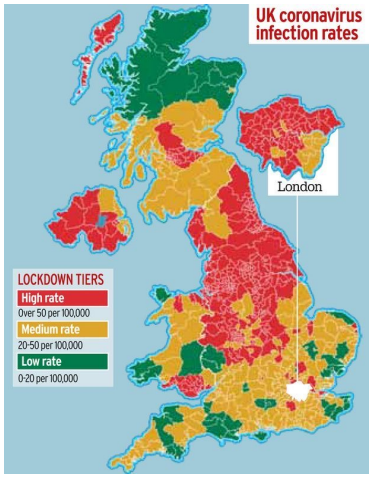
# Green zones in practice: other countries

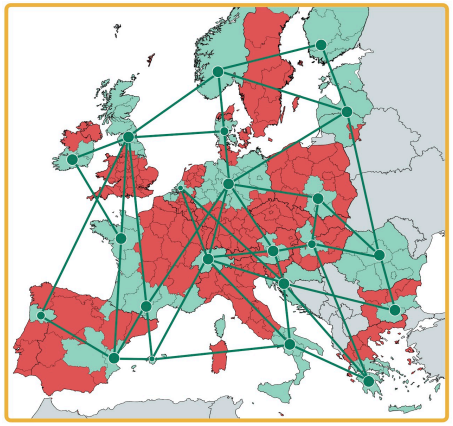


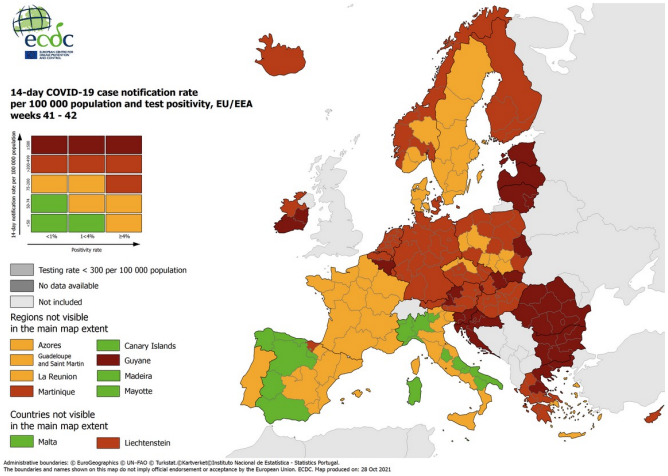

- During the pandemic, many countries have used Green Zoning
- In France, this approach has led to policies that are adaptive, territorial and based on common objective criteria, still used today





# The European Level




- Green zoning was adopted in October 2020 by the European Commission.
- Today, green zoning is the key element of the “OECD initiative for safe international mobility during the COVID-19 pandemic”.

# Key factors that allowed to go from theory to practice

1. Interdisciplinary work in a small group (i.e., notably, health + economic + politics + others)
2. Use theory when there is not enough available data
3. Update and elevate to a higher level, when possible
4. Use the simplest models (i.e., ones that anyone can understand and communicate)
5. Momentum (i.e., mixture of luck and intuition, and boldness)
6. Collaborate with key players (i.e., decision makers, or close to them)

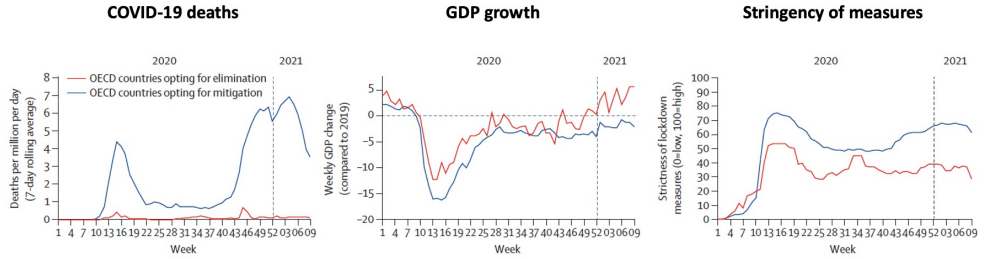
# Possible takeaways

- Hard problem, simple solution. Covid is an unprecedented crisis, thus opening doors to creative solutions. But solutions (models, recommendations) need to remain simple and communicable to the public.
- Interdisciplinarity is relevant. The importance is two-fold : 1) to craft a better solution, and 2) to obtain support from a larger share of the decision-makers.
- Political momentum is the key. Like simplicity and interdisciplinarity, political momentum is an entrance door. But it is the main one, we cannot ignore that.
- Credentials, of course. While simple solutions are preferred, they need to come from high-qualified and/or respected experts.

# Ongoing research on Covid certificates

- We are measuring the impact of Covid certificates in France (on health and the economy). This academic work relies on
  - Innovation diffusion theory
  - Synthetic control
  - Mathematical modelling

# International pluridisciplinary team


**OECD countries opting for elimination:** Australia, Iceland, Japan*, New Zealand, and South Korea (*strong suppression)

**OCDE countries opting for mitigation:** Austria, Belgium, Canada, Chile, Colombia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the UK, and the USA.

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