Evaluation de scénarios renouvelable proposant des mix électriques fiables en France et à La Réunion

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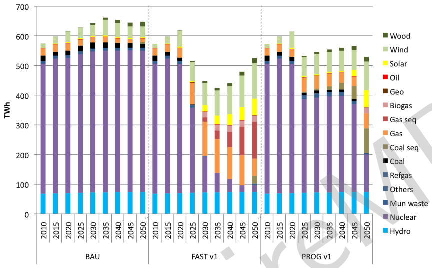
Chaire Modélisation prospective au service du développement durable

système électrique

questions autour de l'intégration du renouvelable

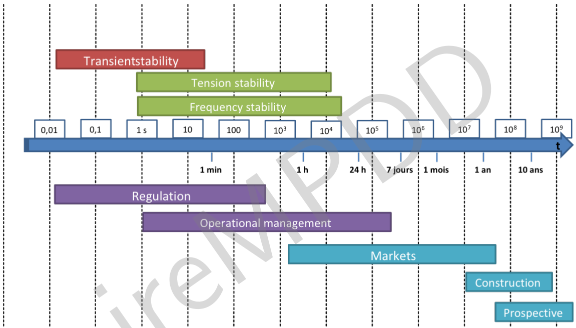


Production électrique taxe et contrainte en volume

☞ Quid de la **pertinence** et **la plausibilité** des mix de production électrique évalués via les exercices de prospective long terme au sens de leur **opération**

L'Europe pendant le blackout de l'Italie (28 Sept. 2003). Source: RTE.

Reconcilier les dynamiques de court et long terme



Source : Adapted from Drouineau 2012 and from Meyer 1998

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- S. Bouckaert, Assessing Smart Grids contribution to the energy transition with long-term scenarios (Contribution des Smart Grids à la transition énergétique: évaluation dans des scénarios long terme), MINES ParisTech PhD Thesis under N. Maïzi direction, 2013.
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Assurer la stabilité du système électrique

i.e. sa capacité à revenir à son état initial d'équilibre suite à une fluctuation de charge

- **Synchronisme** : Assurer la même vitesse angulaire/fréquence des unités (énergie électromagnétique) afin de disposer d'

$$\frac{\lambda_G}{\max_{(i,j)\in\epsilon_G} \|P_i - P_j\|} > 1$$

- **Inertie** : Assurer le maintien de la production et de la transmission (réserve cinétique)

$$H_{cin} = \frac{\sum_k E_{cin}}{S} \geqslant 30s$$

Une **condition suffisante de synchronisme** a été élaborée :

- En s'affranchissant des équations de Kirchhoff
- Par analogie entre la dynamique du système électrique et le modèle de Kuramoto qui décrit le synchronisme d'oscillateurs en interaction
- A partir de la connectivité algébrique du graphe

  grille 2D capturant le comportement du réseau maillé en ses rotors et générateurs donnée par λ_G première valeur propre non nulle.

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4. [V. Krakowski, E. Assoumou, V. Mazauric, N. Maïzi, **Feasible path toward 40% - 100% renewable energy shares for power supply in France by 2050: A prospective analysis**. Applied Energy 171 (2016) 501-522.]
5. [G. Seck, V. Krakowski, E. Assoumou, N. Maïzi, V. Mazauric, **Reliability-constrained scenarios with increasing shares of renewables for the French power sector in 2050**, Energy Procedia (2017) pp. 3041-3048, DOI information: 10.1016/j.egypro.2017.12.442.]
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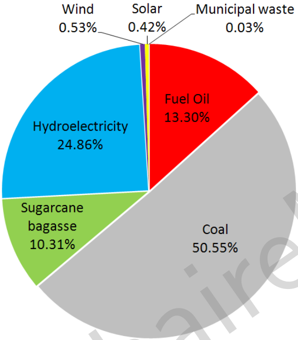
Focusing on the Reunion Island

1. Blessed with high renewable energy potentials
2. Small, weakly-meshed and remoted power system
3. Binding target in 2030: 100% renewable sources in power generation
4. Maximum : 30% RE **intermittency**

The electricity sector in 2008



Source : BPPI - EDF SEI 2009

Electricity production:
2 546 GWh
Renewable energy sources: 36%

Installed capacities

- **Thermal units** (76%):
  - 476 MW
  - Fuels: coal, fuel oil, sugarcane bagasse
- **Hydroelectricity** (20%):
  - Dams: 109,4 MW
  - Run-of-the-river: 11,6 MW
- **Others** (4%):
  - Wind: 16,8 MW
  - Solar PV: 10 MW
  - Municipal Waste: 2 MW

Assessment of two contrasted scenarios

1. **BASE** (with fossil) scenario, reflecting Business as Usual trends

   where imports levels in 2008 :

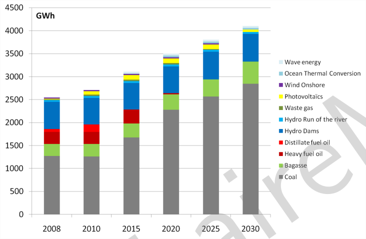
   - coal = 16 395 TJ
   - distillate fuel oil = 408 TJ
   - heavy fuel oil = 3122 TJ

2. **noFOS** (no fossil) scenario, 100% Renewable Energy in 2030

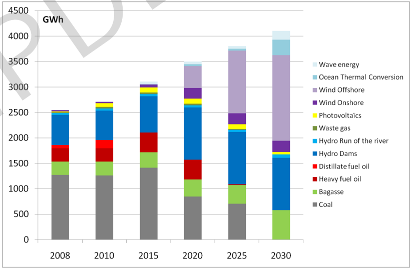
   where fossil fuel imports levels are constrained as follows :

   - ☞ 25 000 TJ in 2010.
   - ☞ 10 000 TJ in 2020.
   - ☞ 0 TJ in 2030.

BAU Scenario : production (GWh)



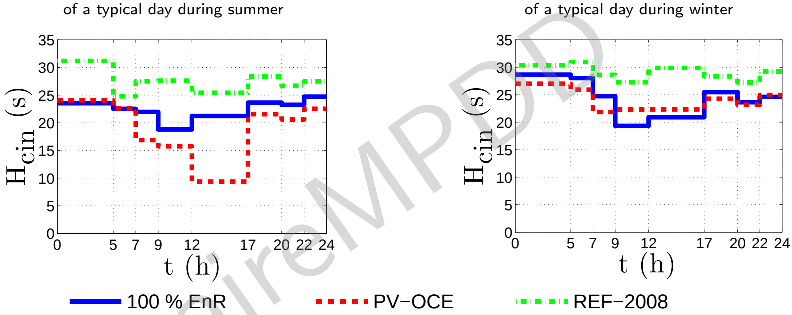
100% Renewable Energy in 2030, production (GWh)



- Ensure only system adequacy
- Need to consider transient stability physical phenomena i.e. **dynamical issues**

Is 30% the maximum share ?

Electricity production mix in 2030



- 100 % EnR : limitation of 30 % of instantaneous power production issued from intermittent sources
- PV-OCE : no constraint on intermittency
- REF-2008 : kinetic reserve level in 2008

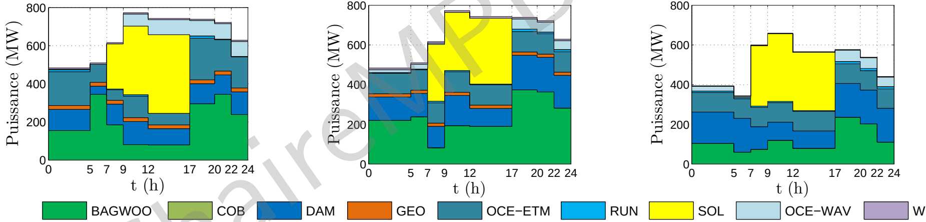
Demand Side Management and Storage

DSM = postponing demand from peak to off-peak periods + EE

Electricity production mix of a typical day during summer in 2030

Without reliability constraint $\forall t : H_{cin,t} \geqslant min(H_{cin,2008})$

Reliability + DSM + Storage (24MW)



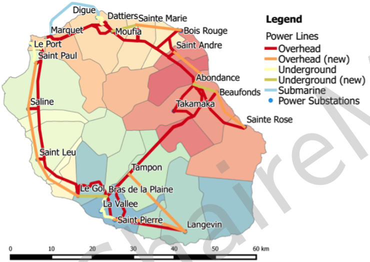
- **share of intermittent sources $\geqslant$ 50%**
- **$\nearrow$ total installed capacities of 9.4 %**

- **share of intermittent sources $\geqslant$ 50%**
- **$\searrow$ total installed capacities of 6 %**

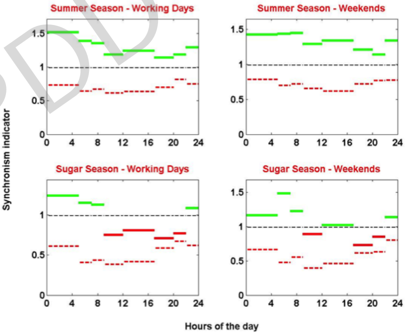
Reunion 100 % RE in 2030: grid issues

☞ Scenario where the reserves indicators are high

Strengthened Reunion grid



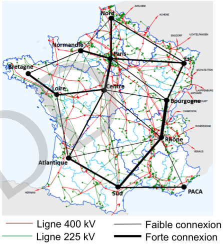
Synchronism indicator



current (dashed) and strengthened grid (solid)

☞ dispersed energy (summer) provides a more resilient grid

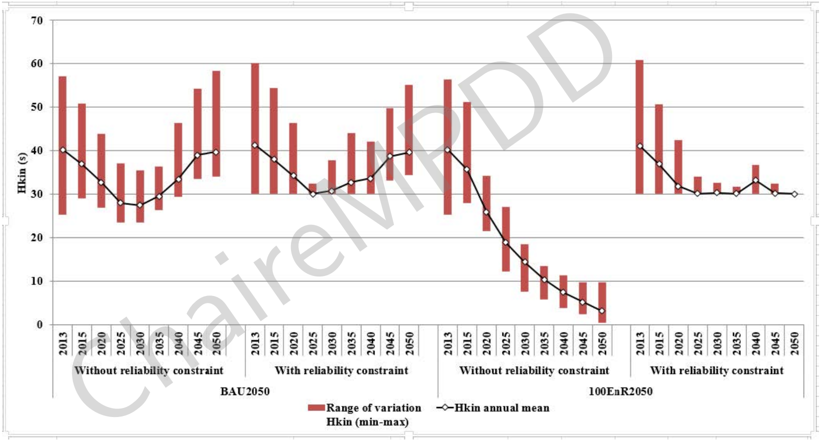
Scénarios d'une France renouvelable



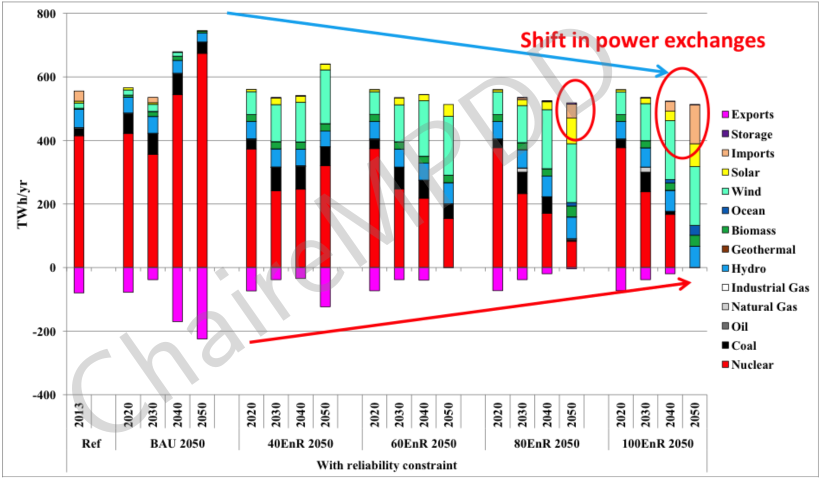
Scenarios

	Years	BAU	40EnR 2050	60EnR 2050	80EnR 2050	100EnR 2050
Nuclear production (max)	2025–2050	NA	50%	50%	50%	50%
RES penetration (min)	2020	NA	27%	27%	27%	27%
	2030	NA	40%	40%	40%	40%
	2050	NA	40%	60%	80%	100%

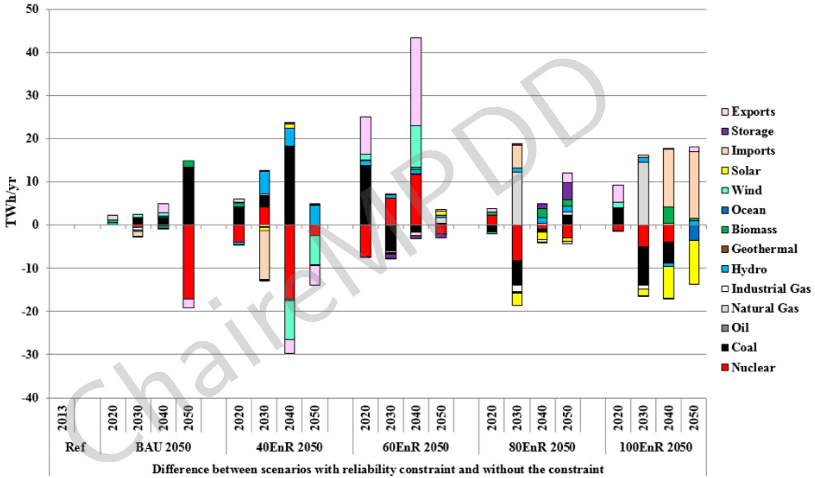
Condition de fiabilité dans le mix électrique



Mix électrique intégrant de 40% à 100% d'ENR

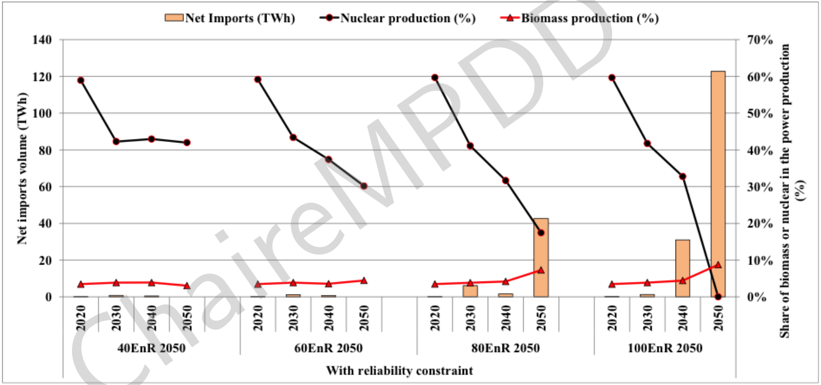


Reliable and non reliable renewable mixes

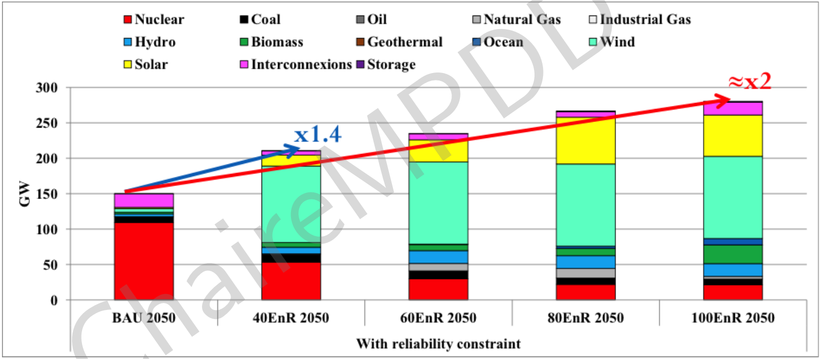


Difference in the French power mix between the scenarios with reliability constraint (top) and without (bottom) constraint.

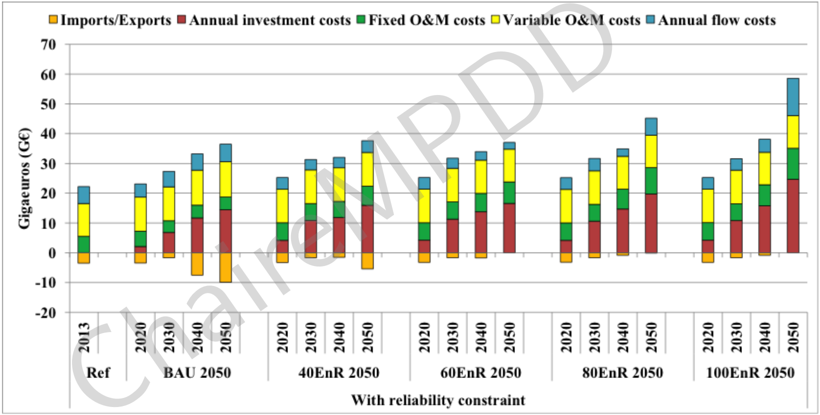
Importations induites par la pénétration massive d'ENR



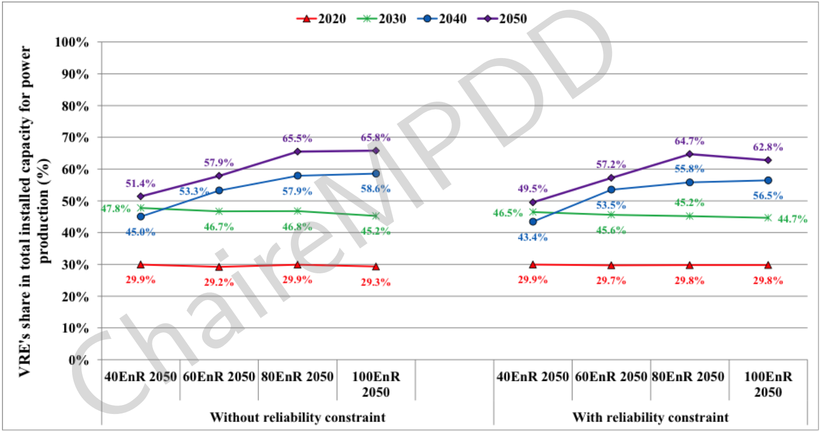
Capacités installées en 2050 pour 40% à 100% d'ENR



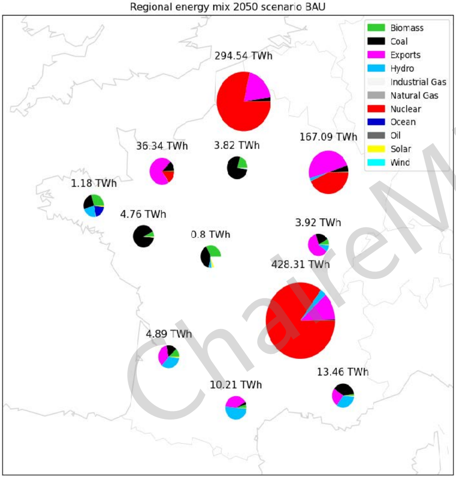
From 40% to 100% renewable in France: costs



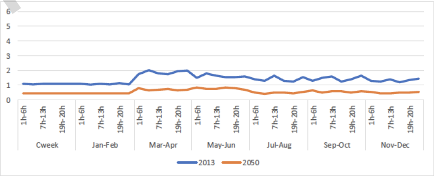
Niveau max de REV pour 40% à 100% d'ENR en France



Condition de Synchronisme pour le BAU

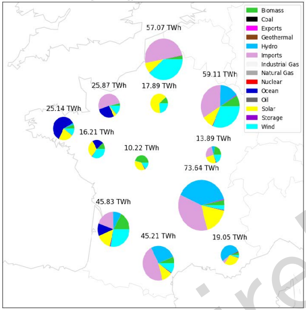


Fluctuations de H_{syn} indicateur de synchronisme

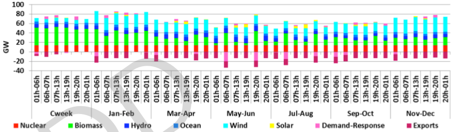


Analyse du mix électrique français 100% renouvelable

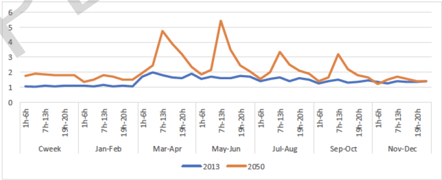
Regional energy mix 2050 scenario 100EnR



Evolution du mix électrique



Fluctuations de H_{syn} indicateur de synchronisme



- Le scénario 100% renouvelable n'est atteint que sous réserve d'importation.
- H_{syn} est toujours supérieur à l'unité (condition de Dörfler). Le synchronisme du système est intrinsèquement stable et il est pertinent de sommer l'ensemble des contributions cinétiques des machines tournantes
- **La décentralisation est favorable au synchronisme mais défavorable à l'inertie du système électrique**

Summary and perspectives

We have developed a unique framework to successfully handle:

- Space-agregation
- Time-reconciliation

At the upper scale:

☞ synchronism of the whole power system may be discussed through the Kuramoto's model; while

☞ kinetic energy balances the load fluctuations.

This approach is dedicated to assess the technical feasibility of future power mix through:

- discuss energy-efficient and environmental-friendly issues;
- take into account intrinsic qualities of the implemented infrastructures.
- Preliminary studies exhibit share of intermittency that do not jeopardize power management.