Le gaz de schiste dans la transition énergétique

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Journées de recherches en sciences sociales
9èmes JRSS – Nancy
10–11 décembre 2015

Energy transition

- The energy transition from a high-carbon present where the world economy burns massively polluting fossil fuels to a low-carbon future where energy will be produced by clean and renewable means is unavoidable if we want to fight climate change seriously.
- The obstacles are massive:
  - fossil fuels have since the Industrial Revolution shaped our economy and even our civilization;
  - at the moment no energy is at the same time abundant, clean, safe and (reasonably) cheap, and the candidates to the replacement of fossil fuels all have their drawbacks.
- What can be the role of shale gas in energy transition?

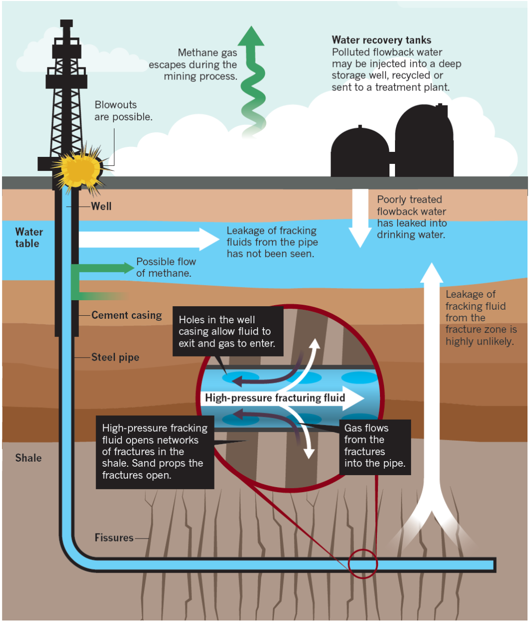
Shale gas in France

- In France, the Jacob law of July 13th, 2011 bans hydraulic fracturing ("fracking"):
  "*Under the Environment Charter of 2004 and the principle of preventive and corrective action under Article L. 110-1 of the Environment Code, exploration and exploitation of hydrocarbon liquids or gas by drilling followed by hydraulic fracturing of the rock are prohibited on the national territory.*"
- Exploration licences cancelled.
- Schuepbach complains to the court that this law is unfair and unconstitutional but the Constitutional Court confirms the ban on October 8th, 2013.
- French President François Hollande says France will not allow exploration of shale gas as long as he is in office.

- This position is supported by a majority of the population:
  - IFOP survey, Sept. 13, 2012: 74% of the respondents are opposed to shale gas exploitation;
  - BVA survey, Oct. 2, 2014: 62%.
  - This is greater than the opposition to nuclear energy, which provides most of France's electricity.
- France and Bulgaria are the only European Union countries to ban shale gas.

Arguments in favor of the ban

1. Fracking is dangerous and environmentally damaging:
   - pollution of surface water (through disposal of fracturing fluids);
   - pollution of groundwater (through accidental leakage of fracking fluids from the pipe into potable aquifers);
   - seismic vibrations caused by the injection of water underground;
   - concerns over landscape (lot of wells).
2. Global warming: we should reduce drastically the use of fossil fuels, not find new ones. Postpones the transition to clean renewable energy.

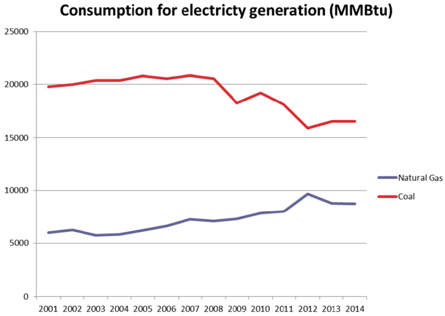

Methane gas escapes during the mining process.
Water recovery tanks
Polluted flowback water may be injected into a deep storage well, recycled or sent to a treatment plant.
Blowouts are possible.
Well
Water table
Leakage of fracking fluids from the pipe has not been seen.
Poorly treated flowback water has leaked into drinking water.
Possible flow of methane.
Leakage of fracking fluid from the fracture zone is highly unlikely.
Cement casing
Holes in the well casing allow fluid to exit and gas to enter.
Steel pipe
High-pressure fracturing fluid
High-pressure fracking fluid opens networks of fractures in the shale. Sand props the fractures open.
Gas flows from the fractures into the pipe.
Shale
Fissures

Arguments against the ban

- Natural gas is less polluting than other fossil fuels (oil, and particularly coal). Good substitute for coal.
- IMF, 2014: "*Natural gas is the cleanest source of energy among other fossil fuels (petroleum products and coal) (...). The abundance of natural gas could thus provide a "bridge" between where we are now in terms of the global energy mix and a hopeful future that would chiefly involve renewable energy sources.*"

Shale gas in the US

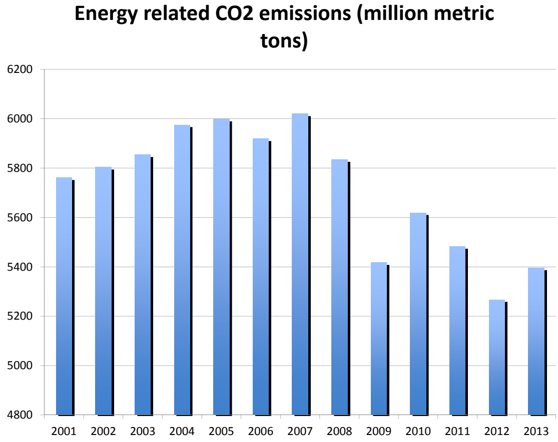
- 2nd coal producer, 2nd coal consumer, top (shale) gas producer
- Shale gas is gradually replacing coal for electricity generation.



- The US shale boom has allowed to create jobs, relocate some manufacturing activities, lower the vulnerability to oil shocks, and impact positively the external balance (IMF, 2014).

- US 2nd CO_2 emitting country
- CO_2 emissions regulation by the Clean Air Act since 2011; 26% reduction target over 2005-2025
- The US "position as the top natural gas producer (...) not only can provide (...) cheap power, but it can also help reduce [US] carbon emissions." (President Obama, June 25, 2013)
- Industry and academic support (eg MIT 2011 report)

- Coal-gas substitution contributes to effectively reduce US CO_2 emissions



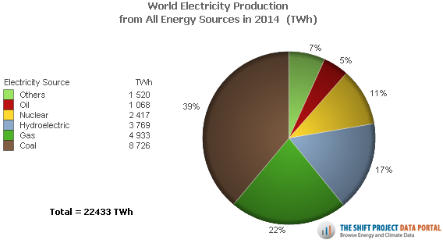
- Is shale gas a good option to reduce CO_2 emissions?
  - If it replaces coal, maybe.
  - If it replaces nuclear, no
- Has shale gas other advantages?
  - Energy security.
  - Substitution to importations.
  - Other?

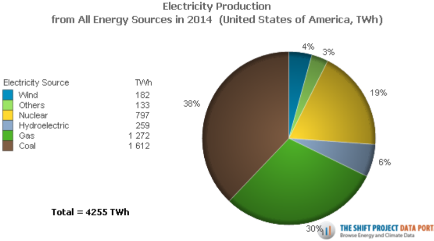
Research questions

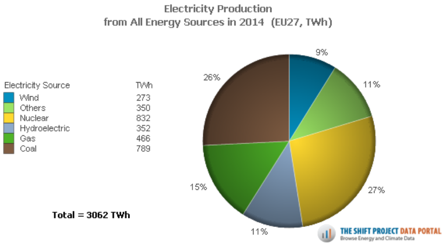
- Does climate policy justify developing more shale gas, in spite of environmental local damages? The US and European cases.
- Does developing more shale gas imply postponing the switch to clean renewable energy?
- What would be the consequences of a moratorium on shale gas in Europe, in terms of costs and welfare?
- Is a unilateral coal-gas substitution strategy to reduce CO_2 emissions limited by coal leakage?

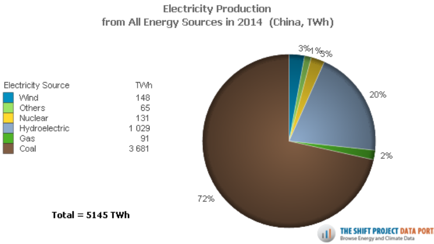
Research program

- Should we extract the European shale gas? The effect of climate and financial constraints.
  Fanny Henriet (PSE, CNRS) & Katheline Schubert (PSE, U. Paris 1).
- Unilateral Cap on CO2 Emissions and Gas to Coal Substitution: Is the Cure worse than the Disease?
  Julien Daubanes (ETH), Fanny Henriet, Katheline Schubert.


World Electricity Production
from All Energy Sources in 2014 (TWh)
Electricity Source
TWh
Others 1 520
Oil 1 068
Nuclear 2 417
Hydroelectric 3 769
Gas 4 933
Coal 8 726
Total = 22433 TWh
7%
5%
11%
17%
22%
39%
THE SHIFT PROJECT DATA PORTAL
Browse Energy and Climate Data


Electricity Production
from All Energy Sources in 2014 (United States of America, TWh)
Electricity Source
TWh
Wind 182
Others 133
Nuclear 797
Hydroelectric 259
Gas 1 272
Coal 1 612
Total = 4255 TWh
4%
3%
19%
6%
30%
38%


Electricity Production
from All Energy Sources in 2014 (EU27, TWh)
Electricity Source
TWh
Wind 273
Others 350
Nuclear 832
Hydroelectric 352
Gas 466
Coal 789
Total = 3062 TWh
9%
11%
27%
11%
15%
26%
THE SHIFT PROJECT DATA PORTAL
Browse Energy and Climate Data


Electricity Production
from All Energy Sources in 2014 (China, TWh)
Electricity Source
TWh
Wind 148
Others 65
Nuclear 131
Hydroelectric 1 029
Gas 91
Coal 3 681
Total = 5145 TWh
3%
1%
3%
20%
2%
72%

The model (1)

- Hotelling-like model of electricity generation.
- Electricity initially produced by coal-fired power plants.
- Two other energy sources, shale gas and solar, may be developed and used in electricity generation.
- The 3 resources are perfect substitutes.
- Coal is abundant but very polluting.
    - Pollution intensity: θ_d.
    - Marginal production cost: c_d.
- Shale gas is non-renewable, and also polluting but less than coal.
    - Pollution intensity: $\theta_e \leq \theta_d$ (Heath *et al.* 2014).
    - Marginal production cost: $c_e < c_d$ (EIA 2014).
    - Marginal local damage: d.
    - Reserves X_e endogenous.
    - Exploration cost $E(X_e)$, with $E'(X_e) > 0$ and $E''(X_e) > 0$, as in Gaudet and Lasserre 1988. Must be paid at date 0. Actual extraction may be postponed to a later date.

The model (2)

- Solar is abundant and clean.
  - Marginal production cost: $c_b > \max(c_e + d, c_d)$.
  - Fixed R&D cost: $CF(t)$, with $CF'(t) < 0$ (exogenous technical progress).
- Combustion of coal and shale gas generates carbon emissions that accumulate in the atmosphere:

$$\dot{Z}(t) = \theta_e x_e(t) + \theta_d x_d(t)$$

  No natural decay.
- Climate policy: cap on the atmospheric carbon concentration $\overline{Z}$ (Chakravorty *et al.* 2006).

	reserves		resources	
	EJ	GtC	EJ	GtC
conventional oil	4 900 – 7 610	98 – 152	4 170 – 6150	83 – 123
unconventional oil	3 750 – 5 600	75 – 112	11 280 – 14 800	226 – 297
conventional gas	5 000 – 7 100	76 – 108	7 200 – 8 900	110 – 136
unconventional gas	20 100 – 67 100	307 – 1026	40 200 – 121 900	614 – 1 863
coal	17 300 – 21 000	446 – 542	291 000 – 435 000	7 510 – 11 230
total	51 050 – 108 410	1002 – 1940	353 850 – 586 750	8 543 – 13 649
Reserves are those quantities able to be recovered under existing economic and operating conditions; resources are those whose economic extraction is potentially feasible.				

Table : Estimates of fossil reserves and resources, and their carbon content. Source: IPCC WG III AR 5, 2014, Chapter 7 Table 7.2

coal	shale	unconventional	conventional
980	470	460	450

Table : Median estimate of life cycle GHG emissions (g CO_2eq/kWh) from electricity generated using coal or different types of natural gas. Source: Heath *et al.*, 2014

	levelized capital cost	fixed O&M	variable O&M including fuel	transmission investment	total
conventional coal	60	4.2	30.3	1.2	95.6
natural gas-fired CC	14.3	1.7	49.1	1.2	66.3
solar PV	114.5	11.4	0	4.1	130
solar thermal	195	42.1	0	6.0	243

Table : US average levelized cost of electricity (2012 $/MWh). Source: EIA, 2014a

The social planner's program

SP chooses:

- extraction and production rates $x_d(t)$, $x_e(t)$, $x_b(t)$,
- amount of shale gas developed X_e,
- date T_b at which the investment in solar plants is made,

which maximize the discounted sum of utilities minus costs, under the resource constraint (shale gas) and the climate constraint.

Constrained optimal price path (1)

For X_e and T_b given:
FOC, with $\lambda(t)$ the scarcity rent associated to the stock of shale gas and $\mu(t)$ the carbon value:

$$\begin{aligned} u'(x_d(t)) &\leq c_d + \theta_d \mu(t) \\ u'(x_e(t)) &\leq c_e + d + \lambda(t) + \theta_e \mu(t) \\ u'(x_b(t)) &\leq c_b \end{aligned}$$

with equality when the energy is actually used, and

$$\begin{aligned} \dot{\lambda}(t) &= \rho \lambda(t) \\ \dot{\mu}(t) &= \rho \mu(t) \text{ before the ceiling} \end{aligned}$$

Constrained optimal price path (2)

- **Large local damage:** $d > c_d - c_e$ **(the European case)**
  Price path potentially composed of 3 phases:

1. Coal used between 0 and T_e;
2. shale gas used between T_e and T_b;
3. solar used from T_b onwards.

   One (or two) of these phases may not exist.

- **Small local damage:** $d < c_d - c_e$ **(the US case)**
  Again, price path potentially composed of 3 phases:

1. Shale gas used between 0 and T_d;
2. coal used between T_d and T_b;
3. solar used from T_b onwards.

Solution (1)

X_e and T_b chosen optimally:

- X_e s.t.

$$\lambda_0 = E'(X_e)$$

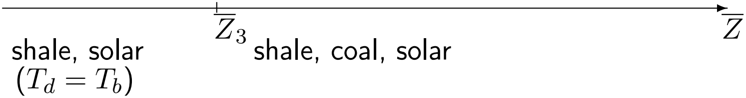
- T_b s.t. marginal benefit of postponing the switch to solar = marginal cost.
- The energy price jumps downwards at date T_b of the switch to solar.

Solution (2)

Optimal succession of energy sources as a function of the stringency of climate policy

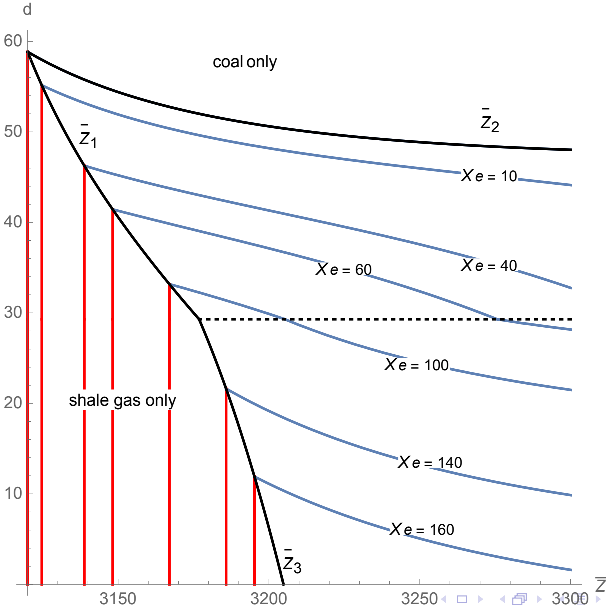
large local damage

small local damage



Solution (3)

The trade-off between local and global damages



Effects of a more stringent climate policy (1)

Large local damage – Europe

- Lenient climate policy: few (or no) shale gas developed. Mainly coal before the ceiling.
- More stringent climate policy:
  - Use of shale gas more interesting because of its lower carbon content $\Longrightarrow$ it is optimal to develop more shale gas, to use it earlier, and to use less coal.
  - The switch to solar happens earlier.

Effects of a more stringent climate policy (2)

Small local damage – US

- More stringent climate policy: the switch to coal happens later while the switch to solar happens earlier.
- When shale gas is not polluting, the more stringent climate policy is, the more shale gas is developed.
- When shale gas is as polluting as coal, the more stringent climate policy is, the less shale gas is developed. Shale gas is evicted by solar.
- If $\theta_e < \theta_d$ and if the price elasticity of demand is low, the more stringent climate policy is, the more shale gas is developed.

Constraint on energy expenditures (1)

Solution

- Present value of total energy expenditures:

$$A_0 = \int_0^\infty e^{-\rho t} \left[c_d x_d(t) + c_e x_e(t) + c_b x_b(t) \right] dt$$
$$+ E(X_e) + CF(T_b) e^{-\rho T_b}$$

- Constraint:

$$A_0 \leq A_0^{\text{ref}}$$

  with A_0^{ref} the present value of energy expenditures absent climate policy.

- Reference absent climate policy:
  - large local damage: coal used alone;
  - small local damage: shale gas used first, then coal.
  - solar never developed.

- The constraint increases the monetary costs of energy generation (extraction, investment and O&M costs) compared to the non-monetary environmental cost (local damage d).
- $\Longrightarrow$ incentive to develop more shale gas and extract it earlier.
- But other effects can play in the opposite direction.
- In the realistic case of a low price elasticity of electricity demand, a binding financial constraint leads to developing more shale gas and postpones the switch to solar.

Simulations (1)

- Model calibrated on European data (except for the marginal cost of shale gas exploration).
- For $d = 3/4c_e$.
  - It is optimal to switch from coal to shale gas in 30 years, and from shale gas to solar in 34 years.
  - Very few shale gas is extracted (5.7% of total European resources are developed).
- For $d = 1/4c_e$, coal is completely evicted by shale gas.
- For $d = 0.4c_e$:
  - it is optimal to switch from shale gas to coal in 60.7 years, and from coal to solar in 62.5 years.
  - Now, very few coal is extracted. The quantity of shale gas developed is equal to 92% of the total recoverable resources.

Simulations (2)

The consequences of a financial constraint – Large local damage

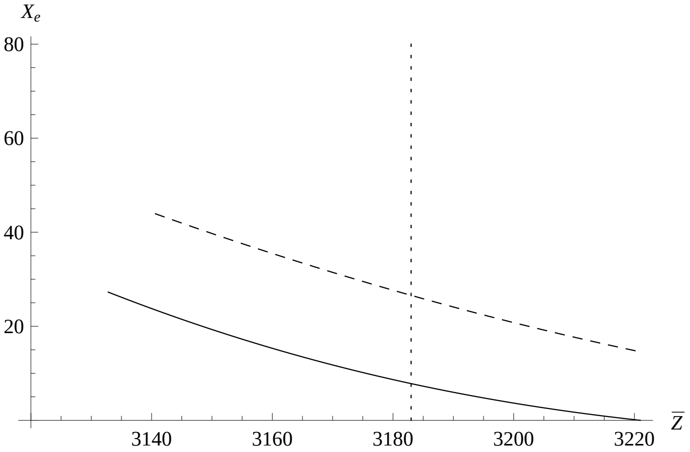


Figure : Quantity of shale gas developed as a function of the value of the ceiling in the reference case (solid line) and the constrained case (dotted line)

Simulations (3)

The consequences of a financial constraint – Large local damage

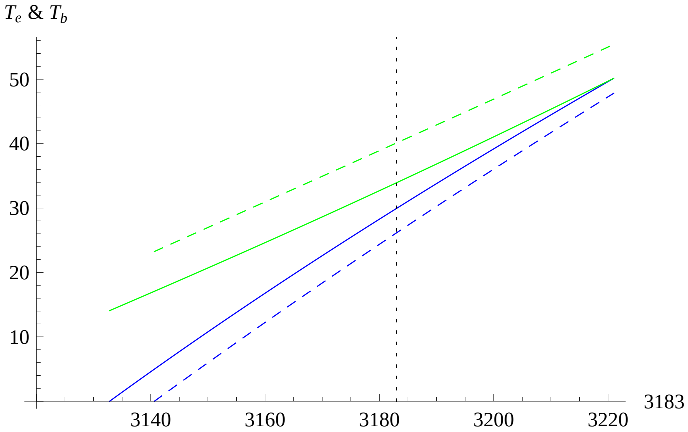


Figure : Switching dates T_e (blue) and T_b (green) as functions of the value of the ceiling in the reference case (solid line) and the constrained case (dotted line)

Simulations (4)

A moratorium on shale gas development

- Electricity generated with coal or solar only.
- Large local damage and lenient climate policy ($\overline{Z} > \overline{Z}_1$): the moratorium leads to the optimal solution. Inconsequential.
- Other cases: for a given climate policy, the moratorium brings forward the switch to solar and increases energy expenditures
- For a large local damage $d = 3/4c_e$, the switch to solar occurs 2 years earlier, energy expenditures increase by 1.8% and intertemporal welfare decrease by 3.6%. Very moderate effect.
- For a small local damage $d = 0.4c_e$, the switch to solar occurs 30 years earlier, energy expenditures increase by 26.7% and intertemporal welfare decrease by 33.5%. Now the negative effect of the moratorium is massive.

For future research

- Political economy aspects:
  Why does France ban not only the *exploitation* of shale gas, but also *exploration* of potential reserves?
- Impact of the subsoil property rights regime on the decision to develop shale gas.
- NIMBY effects in densely populated areas.
- Shale gas and energy security.
- ...

Calibration (1)

Functional forms:

$$u(x) = ax - b\frac{x^2}{2} \Longrightarrow D(p) = \frac{a-p}{b}$$
$$CF(t) = CF_0 e^{-\gamma t}$$
$$E(X_e) = \frac{\varepsilon}{2} X_e^2$$

Calibration (2)

- Unit costs $c_d = 95.6$\$/MWh, $c_e = 66.3$\$/MWh and $c_b = 130$\$/MWh (US levelized cost of electricity from EIA, 2014a).
- Emission coefficients $\theta_d = 0.98$ tCO_2eq/kWh and $\theta_e = 0.47$ tCO_2eq/kWh.
- Rates of discounting and technical progress: $\rho = 0.02$ and $\gamma = 0.03$.
- Initial carbon concentration in the atmosphere: $Z_0 = 400$ ppm.
-
  - Around 50% of total emissions is projected to come from electricity generation.
  - Around 11% of GhG emissions come from the European Union.
  - $\Longrightarrow$ a 3°C target corresponds to a European sectoral ceiling in electricity generation of 408 ppm.

Calibration (3)

- The fixed cost of developing a clean technology at date 0, CF_0, is assumed to be the investment necessary to solve the intermittency problem (infrastructure and storage). It is calibrated using the French Environment and Energy Management Agency report (ADEME, 2015) : 329 Million €/year.
- Demand elasticity at 95.6\$/MWh $= 0.25$ (Alberini *et al.*, 2011).
- Marginal cost of shale gas exploration calibrated using data on US shale wells (EIA Natural Gas Weekly Update).