Don’t we need any integrated carbon indicator in order to manage forests sustainably?

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Background: Forest carbon issues

- Land use changes
- Carbon sequestration by growing forests
- Storage and residence time of carbon in
  - soils,
  - trees
  - forest products
- Removals of roundwood
- Material substitution due to the use of forest products
- Energy substitution due to use of fuelwood/wood residues
- Energy substitution at the end of service life
- Emissions due to forest activities

Background: Literature

- At the macroeconomic level
  - In connection with Climate Convention (UNFCCC and KP)
    - Reporting and accounting
    - Best strategy for the forest sector and climate mitigation
  - In connection also with information towards customers (carbon footprint)
- At the stand level
  - Carbon flows and stocks (still reporting and accounting)
  - Not often comprehensive (sequestration, storage, substitution)
  - Not often in value with the use of discounting.
- Some references however.

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Background: Carbon and indicators

- Pan european criteria and indicators of sustainable forest management describe mainly the carbon sink
- Indicators should be useful for all issues quoted previously
- An integrated indicator should be useful for decision makers
- This would allow to carry out multicriteria analyses.
- One single indicator is waited for carbon (and another for biodiversity !!!)

Background: History of forest economics

- Similar discussion now with carbon as those three centuries ago about the best rotation age
  - To reduce the wood shortage
  - To increase owners' revenues.
- Réaumur (1721) : the highest mean annual increment
- Buffon (1734): the higghest current annual increment (!)
- Duhamel du Monceau (1764): particular case of a fully regulated forest
- Varenne de Fenille (1791) gives the rule to find the highest mean annual increment (equal to the current increment) and understands the role of the discount (interest) rate.

Background: Conclusion for action

- Economics is useful to think about the right indicator with the use of the concepts of
  - Opportunity cost (avoided emissions)
  - Discount rate.

Contents

- Background (done)
- Quantification of carbon issues
- Combination in a single indicator
- Numerical application.

Quantification with simplifications

- In order to avoid complex formulations, main simplifications are implemented:
  - Evenaged stands
  - No thinnings
  - No annual administrative costs nor annual revenues
  - Tree mortality is not explicitly mentioned
  - Only wood and carbon economies are considered
  - The use of half-life

- Because of the two first simplifications, the application case concerns poplar groves.

Quantification of plantation

- The plantation costs are considered separately because they are allocated
  - partly to wood production
  - and partly to carbon sequestration.

$$-Do\frac{1}{1-e^{-rn}}$$

- where
  - ***Do*** is the plantation cost (at time 0) (3 500 €/ha)
  - ***r*** is the discount rate (4%)
  - ***n*** is the rotation age (to be determined)
  - the fraction expresses an infinite series of rotations beginning at time 0.

Quantification of wood economy

$$p(n).q(n).V(n)\frac{e^{-rn}}{1-e^{-rn}}$$

- where
  - *n* is the rotation age
  - ***p(n)*** is the stumpage price at age *n* (up to 45 €/m3)
  - ***V(n)*** is the growing stock (up to 300 m3/ha)
  - ***q(n)*** is the marketed share of this growing stock (0 to 0.6)
  - the fraction expresses an infinite series of rotations beginning at time n

Quantification of sequestration

$$p_c.c.z.(\int_o^n V'(t).e^{-rt}dt)\frac{1}{1-e^{-rn}} \approx p_c.c.z.V(n).e^{-rd}\frac{1}{1-e^{-rn}}$$

- where
  - *V(n)* is the growing stock
  - *V'(t)* is its current increment
  - ***d*** is the half-life of the stock growing from 0 to n
  - ***z*** is the expansion factor to branches and roots (1.6)
  - ***c*** is the conversion factor from m^3 to tons of CO_2 (0.76)
  - p_c is the price of the ton of CO_2 (0 to 100 €/tCO_2)

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Quantification of substitution

$$p_c.a(n).c.q(n).V(n).e^{-rn}\frac{1}{1-e^{-rn}}$$

- where
  - *V(n)* is the growing stock
  - *q(n)* is the market (product) share of the growing stock
  - *c* is the conversion factor from m^3 to tons of CO_2 (0.76)
  - ***a(n)*** denotes the avoided emissions due to forest products
  - p_c is the price of the ton of CO_2 (from 0 to 100 €/tCO_2)
- **a(n)** could reach 0.67 tCO_2/tCO_2 for energy substitution and 2.1 tCO_2/tCO_2 for material substitution (LCA, Rüter, 2012). Here it depends heavily on the end-product mix

Quantification of emissions (products)

$$p_c.c.q(n).V(n).e^{-r(n+h)}\frac{1}{1-e^{-rn}}$$

- where
  - *V(n)* is the growing stock
  - *q(n)* is the market (product) share of the growing stock
  - *c* is the conversion factor from m^3 to tons of CO_2 (0.76)
  - p_c is the price of the ton of CO_2 (from 0 to 100 €/tCO_2)
  - ***h*** stands for the half-life of the product mix.

Quantification of end of life substitution

$$p_c.a'.c.q'.q(n).V(n).e^{-r(n+h)}\frac{1}{1-e^{-rn}}$$

- where
  - *V(n)* is the growing stock
  - *q(n)* is the market (product) share of the growing stock
  - *q'* : share of products used for energy at their end of life (0.2)
  - *c* is the conversion factor from m³ to tons of CO_2 (0.76)
  - ***a'*** denotes avoided emissions due to forest products (0.3)
  - p_c is the price of the ton of CO_2 (from 0 to 100 €/tCO_2)
  - *h* stands for the half-life of the product mix (0 to 20 years).

Quantification of emissions (non products)

$$p_c.c.(z-q(n)).V(n).e^{-r(n+k)}\frac{1}{1-e^{-rn}}$$

- where
  - *V(n)* is the growing stock
  - *q(n)* is the market (product) share of the growing stock
  - *z* is the expansion factor to branches and roots
  - *c* is the conversion factor from m³ to tons of CO_2 (0.76)
  - p_c is the price of the ton of CO_2 (from 0 to 100 €/tCO_2)
  - ***k*** stands for the half-life of the non products (10 years)

Quantification of land-use change

$$p_c.(S_f - S_a).e^{-rl}$$

- where
  - S_f is the carbon stock in forest soils at steady state
  - S_a is the carbon stock in the soil before afforestation
  - p_c is the price of the ton of CO_2 (from 0 to 100 €/tCO_2)
  - l stands for the half-life for the constitution of the new carbon stock in soils.
- This phenomenum occurs only once.
- A variation of the carbon stock of soils could also be taken into account for each regeneration period.
- These changes are not taken into account in what follows.

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Combination

Faustmann

- Plantation costs $$-Do\frac{1}{1-e^{-rn}}$$
- Wood $$p(n).q(n).V(n)\frac{e^{-rn}}{1-e^{-rn}}$$
- Carbon $$p_c.c.V(n).e^{-rn}\frac{1}{1-e^{-rn}}(A+B+C+D+E)$$
  - Sequestration $$A=z.e^{r(n+d)}$$
  - Substitution $$B=a(n)+q(n)$$
  - Emissions (products) $$C=q(n).e^{-rh}$$
  - End of life substitution $$D=a'.q'.q(n).e^{-rh}$$
  - Emissions (non products) $$E=[z-q(n)].e^{-rk}$$

Case-study: reference scenario

- Main features of the scenario
  - Mentioned previously
  - p_c=20 €/tCO2
- Results
  - Faustmann: 1250 €/ha and 23 years
  - Wood (and partly plantation costs): 3918 €/ha and 22 years
  - Carbon (and partly plantation costs): 3331 €/ha and 27 years
  - Total: 7103 €/ha and 24 years
- For 24 years
  - Sequestration : 1211 €/ha
  - Substitution: 5561 €/ha
  - Emissions: -2274 €/ha

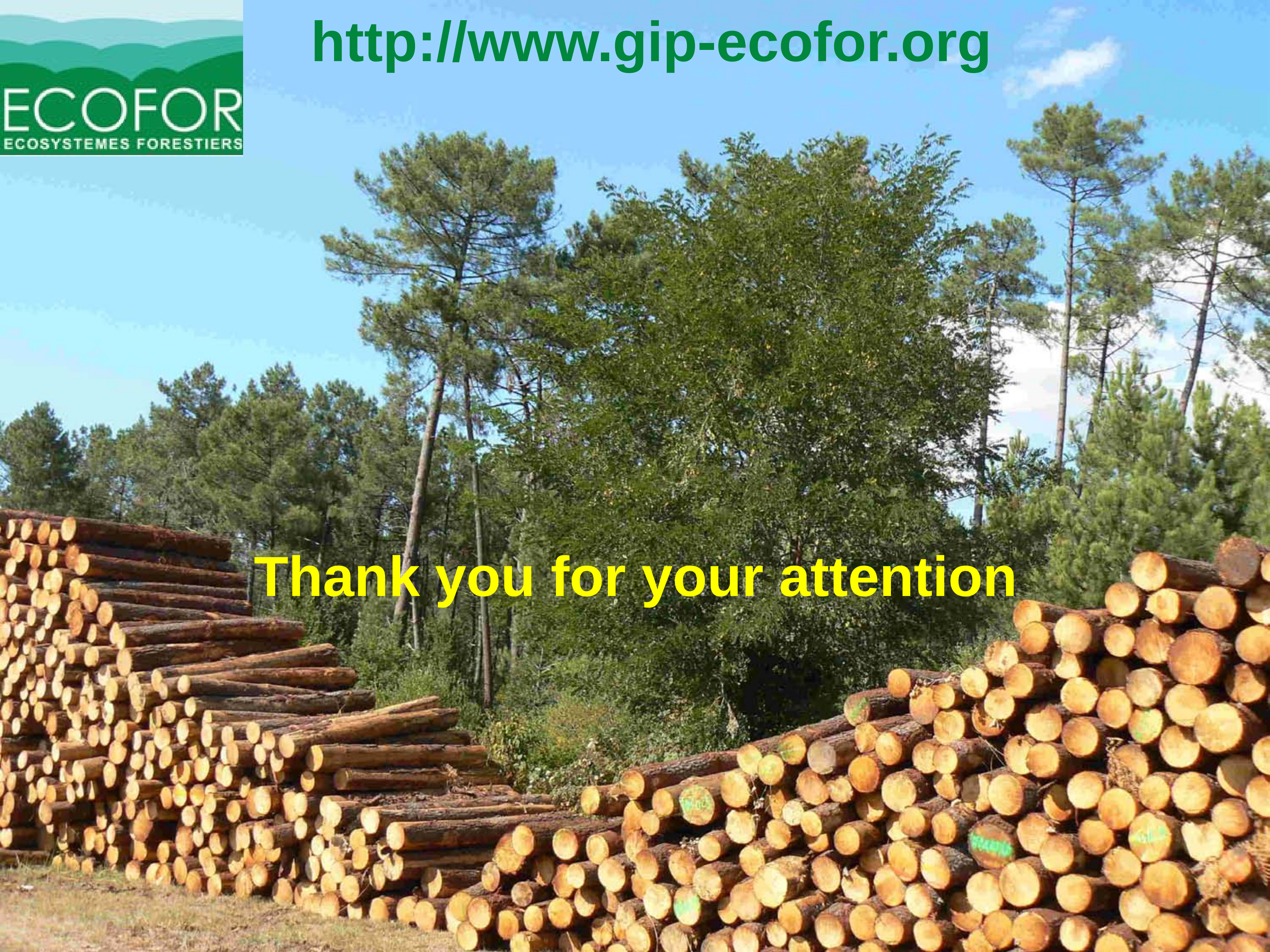
Case-study: scenarios

- Main features of the scenarios
  - p_c=100 €/tCO2
  - Increase of p_c along time from 20 to 100 €/tCO2

	Reference	High carbon price	Increasing carbon price
Wood	3918 €/ha – 22 years	6127 €/ha -21 years	6052 €/ha – 21 years
Carbon	3331 €/ha – 27 years	25258 €/ha – 27 years	32077 €/ha – 30 years
Global	7103 €/ha – 24 years	30753 €/ha – 25 years	36077 €/ha – 30 years
Sequestration Substitution Emissions	5561 €/ha 2605 €/ha -2274 €/ha	27739 €/ha 13131 €/ha -11881 €/ha	33899 €/ha 14164 €/ha -11592 €/ha

Conclusions

- It is possible to generalise the Faustmann formula to take into account sequestration, substitution and the residence time in forests and in forest products
- The complexity is mainly due to the number of different cases to be analysed
- Additional information could be carried out concerning thinnings, change in soil carbon stock
- The uncertainty lies in parameters
- Sensitivity analyses can be done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