Development of the bioenergy supply chain in TIAM-FR

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1. Bioenergy supply chain in TIAM-FR
2. New structure of bioenergy sector in TIAM-FR
3. Calibration of bioenergy sector in TIAM-FR
4. Scenario results of model
5. Conclusions
Current structure and challenges

Current decomposition of biomass supply chain
- Rough aggregation in 6 primary biomass resources
  - BIOCRP, BIOSLD (3 price levels), BIOGAS, BIOLIQ, BIOBIN, BIOBMU

Major challenges
- Direct control on energy crops
  - Actual policy trends: Interdiction of bioenergy from edible sources
- Different uses of crop types
  - sugar/starch crops vs oil crops
- Enlarge choice of biomass resources
  - Different crops (land use competition)
  - Introduction of new energy crops (Perennial grasses, Jatropha, Cassava, etc.)
  - Different solid biomass: Agricultural residues, forestry residues, fuelwoods
- International bioenergy market
  - Import/export vs production, Increase or decrease in domestic supply capacity
Current structure and challenges

- Actual chain of energy crops

- Actual chain of solid biomass
Current structure and challenges

- **Actual chain of energy crops**
  - **BIOCRP (Energy crops)**
    - 1st generation bioethanol w/o CCS
    - 1st generation biodiesel w/o CCS
    - 2nd generation bioethanol w/o CCS
    - Use as BIOBSL (final biosld)
    - Electricity and Heat production (Incl. CHP)

- **Actual chain of solid biomass**
  - **MINBIOSLD1 (Low price)**
  - **MINBIOSLD2 (Mid price)**
  - **MINBIOSLD3 (High price)**
    - FT biodiesel w/o CCS
    - Synth Diesel Hydrothermal upgrading
    - Use as BIOBSL
    - Electricity and Heat production (Incl. CHP)
New bioenergy chain (energy crops)

Cost per hectare ($/ha)  Availability surface (Kha)

Productivity (t/ha)  MINBIOSRF

Sugarcane surface  Sugar beet surface  Sorghum surface  Miscanthus surface  Switchgrass surface  Palm fruits surface  Soybeans surface  Sunflower surface

Energy conversion (PJ/kt)

1st generation of bioethanol  Electricity and Heat production (Incl. CHP)  2nd generation of biodiesel  Direct utilization (BIOBSL)

1st generation of biodiesel (Hydrotraitement)

Sugarcane production  Sugar beet production  Sorghum production  Miscanthus production  Switchgrass production  Palm fruits production  Soybeans production  Sunflower production

Sugar/Starch crops  BIOCRP grouping

Oil extraction rate

Palm oil  Soybean oil  Sunflower oil

1st generation of bioethanol  Vegetable oils grouping

Energy conversion (PJ/kt)

Energy conversion (PJ/kt)  Energy conversion (PJ/kt)  Energy conversion (PJ/kt)

17/11/2016
New bioenergy chain (energy crops)

Inter-regional trade (Primary resources)

Inter-regional trade (Secondary resources)

Inter-regional trade (Final energy)

Available surface (Kha)

MINBIOSRF

Cost per hectare ($/ha)

Productivity (t/ha)

Sugarcane production

Sugar beet production

Sorghum production

Miscanthus production

Switchgrass production

Palm fruits production

Soybeans production

Sunflower production

Energy conversion (PJ/kt)

Sugar/Starch crops

Electricity and Heat production (Incl. CHP)

2nd generation of bioethanol

Direct utilization (BIOBSL)

1st generation of biodiesel

Vegetable oils grouping

1st generation of biodiesel (Hydrotraitement)

17/11/2016
New bioenergy chain (solid biomass)

- New structure for solid biomass

MINBIOWOOD → Fuelwood → BIOSAW → Wood pellets and torrified pellets

MINBIOPRC → Wood processing residues → BIOSAW → Charcoal production

MINBIOLOG → Wood logging residues → BIOSAW → FT biodiesel w/o CCS

MINBIOARSP → Food(crop) processing residues → BIOSAW → Synth Diesel Hydrothermal upgrading

MINBIOARSH → Crop harvesting residues → BIOSLD → Direct utilization (BIOBSL)

Cost (M$/PJ) → Electricity and Heat production (Incl. CHP)

2nd generation of biofuel
New bioenergy chain (solid biomass)

- New structure for solid biomass

Inter-regional trade (Primary resources)
- MINBIOWOOD
- MINBIOPRC
- MINBIOLOG
- MINBIOARSP
- MINBIOARSH

Cost (M$ PJ)

Inter-regional trade (Final energy)
- Wood pellets and torrified pellets
- Charcoal production
- FT biodiesel w/o CCS
- Synth Diesel Hydrothermal upgrading
- Direct utilization (BIOBSL)
- 2nd generation of biofuel
- Electricity and Heat production (Incl. CHP)

Fuelwood
- Wood processing residues
- Wood logging residues
- Food(crop) processing residues
- Crop harvesting residues

BIOSAW
BIOSLD
Biomass potential estimation

- **Applied approach**
  - Surface-oriented (Available surface for energy crops production)

- **Methodology for crops potential estimation**
  - «Food-first approach »: Priority in food supply (Preliminary allocation of surface for food)

\[
\text{Landavl}_{i,j} = \text{Agrland}_{i,\text{baseyear}} + \text{Grass and other wooded land}_{i,\text{baseyear}} - \text{Agrland}_{i,j} - \text{livestockland}_{i,j} - \text{builtupexp}_{i,j} - \text{Protected land}_{i} - \text{Preservation factor} \times \text{other wooded land}_{i,j} - \text{Severe nutrient quality land}_{i}
\]
Biomass potential estimation (crops)

- **Food demand projection**

\[ \text{Domestic production} = \{ \text{Population} \times (\text{Food} + \text{Food processing}) + \text{other uses} + \text{Feed} + \text{Wastes} + \text{Seeds} \} \times \text{SSR} \]

- Consumption per capita: «World agriculture: towards 2030/2050 Prospects for food, nutrition, agriculture and major commodity groups – FAO »
- Demographic evolution per country: «United Nations’ population projection revision 2012 »
- SSR (Self sufficiency ratio) per country, per commodity: Food balance sheet –FAO
  - Constant SSR until 2050

- **Feed demand projection**

\[ \text{Feed}_{i,\text{year,region}} = \text{Demand}_{j,\text{year,region}} \times Fco_{i,j,\text{prod}} \times Fce_{j,\text{prod}} \]

- 3 sources of feed: grasses and fodder, feed crops, residue
- 5 types of animal products: Bovine, Dairy products, Sheep/goat, Pig, Poultry
- 2 types of livestock production system: Mixed (Pasture + Farm), Landless (Only Farm)
- FCO: Feed composition among 3 sources of feed
- FCE: Feed conversion efficiency (animal product / feed)

- **Yield projection**

- GAEZ assessment (IIASA,FAO) Agro-climatically attainable yield for 2030, 2050
- Irrigation vs Rainfed (several scenarios - between 0pp evol and 40pp evol)
Biomass potential estimation (crops)

- Final available land estimation

Cultivated Area:
In case of expansion, allocation to grass and other wooded land

Forest (Preserved)

Grass and other wooded land

Non productive land
Water bodies

Land cover

Suitable land for cultivation

Soil nutrient quality (severe to no constraint)

Cultivated land

Grass and other wooded land

Land demand for food and feed crops

Pasture land for livestocks

Preserved other wooded land

Built-up area expansion

Low nutrient quality

Protected land

Available land for bioenergy
Biomass potential estimation (Forestry)

- Solid biomass

Wood supply from forest = Supply (Forest+ Other wooded land + TOF) - Demand

- Wood from forest and other wooded land
  - Main database: FRA2015 (Forest Resource Assessment 2015) - FAO
  - Forest surface * GAI (Gross annual Increment) * BCEF (Biomass conversion factor)
  - \( NAI_{land,region} = GAI_{land,region} - NL_{land,region} \)

\[
GAI_{land,region} = \frac{\left( (GS_{land,region,time} - GS_{land,region,0}) + (F_{land,region,time} - F_{land,region,0}) + (NL_{land,region,time} - NL_{land,region,0}) \right)}{Time - 0}
\]

\( GS_{land,region,time} \) = Total growing stock
\( F_{land,region,time} \) = Total felling trees (Removed woods)
\( NL_{land,region,time} \) = Natural loss (Deadwood stock)

  - Commercial species ratio is applied for economic potential

- TOF (Trees outside forest)

\[
TOF_{region,year} = OLwT_{C,region,year} \times GAI_{forest,region,year} + (OLwTOF_{region,year} - OLwT_{C,region,year}) \times GAI_{other,region,year}
\]
2) TOF (Trees outside forest)

- Constant wood consumption per capita ratio applied

4) Residues (Harvesting/logging, processing)
- RPR (Residue production ratio) from different literature applied for each region and commodity

\[ Residues_{comm,region,year} = Prod_{comm,region,year} \times RPR_{comm,region} \times Recovery_{comm,region} \]
## Biomass potential estimation - Results (crops)

- **Global**: 2,544 Mha (Min: 889 Mha, Max: 3,200 Mha)

### Study Details

<table>
<thead>
<tr>
<th>Study</th>
<th>Type of potential</th>
<th>Regions</th>
<th>Time frame</th>
<th>Land use types</th>
<th>Surplus land area</th>
<th>Potential</th>
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<tbody>
<tr>
<td>WBGU, 2008</td>
<td>Technical</td>
<td>Global</td>
<td>2050</td>
<td>Land suitable for bioenergy cultivation according to the crop functional types in the model, considering sustainability</td>
<td>240 - 500 Mha</td>
<td>34-120EJ/yr</td>
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<tr>
<td>Smeets et al, 2007</td>
<td>Technical</td>
<td>Global</td>
<td>2050</td>
<td>Surplus agricultural land (100%)</td>
<td>730 - 3,590 Mha</td>
<td>215 – 1272 EJ/yr</td>
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<td>Hoggwijk et al., 2003</td>
<td>Technical</td>
<td>Global</td>
<td>2050</td>
<td>Surplus agricultural land, Surplus degraded land</td>
<td>3,300 Mha</td>
<td>8 – 1098EJ/yr</td>
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<tr>
<td>Hoggwijk et al., 2005</td>
<td>Technical</td>
<td>Global</td>
<td>2050-2100</td>
<td>Abandoned agricultural land (100%), Remaining land not for food or material production (10-50%), Extensive grassland</td>
<td>90 - 290 Mha</td>
<td>Total: 311-657 EJ/yr (Climate scenario A1: 657EJ/yr)</td>
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<td>Van Vuuren et al., 2009</td>
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<td>Abandoned agricultural land (75%), Grassland (25%)</td>
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<td>Erb et al., 2009</td>
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<td>2050</td>
<td>Cropland not needed for food and fiber supply intensification of grazing land</td>
<td>230-990 Mha</td>
<td>28-128EJ/yr</td>
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</table>

**Note**: The study types include technical and methodological approaches to estimate biomass potential.
Biomass potential estimation – Results (Forestry)

- Forestry biomass
  - Economic potential: 68 EJ/yr in 2050
  - Technical potential: 114 EJ/yr in 2050

Economic potential of forestry biomass by 2050

- Wood wastes
- Processing residues
- Logging residues
- TOF supply
- Industrial wood demands
- Sustainable forest supply

17/11/2016 70TH SEMI-ANNUAL ETSAP MEETING
Needs for new calibration

- Major challenges (Calibration of biofuel)
  - Mismatching consumption and production of biofuels
    - Missing bioethanol and biodiesel consumption (for all sectors)
    - TRAETH in VT represents the sum of solid biomass, charcoal, biogas and other bio-liquid

### Table 1: IEA Data

<table>
<thead>
<tr>
<th>Component</th>
<th>IEAStats</th>
<th>HARDCOAL, PATFUEL, ANTCOAL, BITCOAL, COKCOAL, PEAT, BKB, BROWN, SUBCOAL, LIGNITE</th>
<th>SBIOMASS</th>
<th>CHARCOAL</th>
<th>GBIOMASS, OBIOLIQ</th>
<th>MUNWASTEN, MUNWASTER</th>
<th>INDWASTE</th>
<th>NATGAS</th>
<th>LPG</th>
<th>MOTORGAS</th>
<th>AVGAS</th>
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#### Existing vehicles

<table>
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<tr>
<th>TechName</th>
<th>TechDesc</th>
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<th>(\text{\textbackslash 2005 final energy}^{\text{D_LNK_EF}})</th>
<th>(\text{\textbackslash 2005 Service Demand}^{\text{CAPUNIT}})</th>
<th>(\text{\textbackslash 2005 - 2000 EFF Mult.}^{\text{\textbackslash 2005 - 2000 EFF}})</th>
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\(\text{\textbackslash 2005 final energy}^{\text{D\_LNK\_EF}}\) = 505.44
Needs for new calibration

- **Major challenges (Calibration of biofuel)**
  - No distinction between carbon dropping biodiesel from Fischer-tropsch, and 1\textsuperscript{st} generation biodiesel
    - BIODST serves both to TRABDL and TRADST
  - Pre-mixed technology for BIODST in TRADST
    - No environmental advantage applied
    - TRADST emission factor is fixed

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**Subres_Altfuel**

**VT_TRA**

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<th>Comm-IN</th>
<th>Comm-OUT</th>
<th>CommDesc</th>
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</table>
Calibration results

- Newly added commodities
  - IEA raw data extraction for biofuels at upstream and also at sector level
  - No pre-mixed technology for FT biodiesel
    - Consumption possibility at end-uses with diesel in each sector (AGRBIODSLD, TRABIODSLD..)
  - Biogas separation for traceability in transport sector (mixing consumption with natural gas)
  - Other bioliquid consumption in previous TRAETH consumption tech for Existing vehicles
  - Mixed consumption of biofuel in process level
  - Wood pellet production and consumption at reference year

<table>
<thead>
<tr>
<th>TechName</th>
<th>TechDesc</th>
<th>Comm-IN</th>
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Existing vehicles

- Calibration of bioenergy sector in TIAM-FR
- Val_Cond: AllRegions
- Pset_Set: Pset_CI: PSET_PN: Cset_CN
- TRMDST000 MEDIUM TRUCK: .00.CFV.DST.EXISTING.STD. TRADST 153.73 0.08
- TRMBIOM000 MEDIUM TRUCK: .00.AFV.BIOM.EXISTING.STD. TRABiom 0.00 0.07
Calibration results

- Biomass extraction calibration
  - Crops, vegetable oils
    - Minimum production for biofuel uses at 2010: OECD agricultural outlook
    - Maximum consumption: FAO food balance sheets, item: other uses
  - Woods and residues
    - Minimum production: FAO forestry database
  - Pellets
    - Minimum production: Ecofys

- International trades
  - Crops, vegetable oils
    - Inter-regional exchange: FAO trade matrix
  - Wood and residues
    - Regional total import/export: FAO forestry database
  - Bioethanol, biodiesel and pellets
    - Inter-regional exchange: USDA, EUROSTAT, ECOFYS, scientific literature
    - Regional total import/export: IEA
  - Primary solid biomass: regional total from IEA
Primary results (BAU, Factor2)

- **Final energy consumption**
  - Final bioenergy consumption increases (58% in liquid fuels, 31% in solid biomass) over BAU scenario
  - Total bioenergy consumption in 2050 (BAU : 50 EJ, Factor2 : 67 EJ)
Primary results (BAU, Factor2)

- **Crops production for bioenergy use**
  - Under 2nd generation of biofuel, perennial grasses become dominant
  - Total crops production increases from 6 EJ in 2010 to 42 EJ in 2050
Primary results (BAU, Factor2)

Bioenergy trade by 2050

- Trade amounts increase from 2.2 EJ to 6.7 EJ at global bioenergy trade
- Main biodiesel traders (Importer: JPN, WEU), (Exporter: AUS, CAN, ODA)
- Main bioethanol traders (Importer: CAN, USA, WEU, JPN), (Exporter: CHI, FSU, ODA)
- Main Pellets traders (Importer: USA, IND), (Exporter: CSA, CAN)
Conclusions

- Improved structure of bioenergy in TIAM-FR
  - Surface-based crops production
  - Primary solid biomass disaggregation
  - Wood pellets and torrified pellets integration
    - Pellet production tech.
    - Electricity production tech (Stand alone, co-firing)
  - International trade of bioenergy implementation
    - Primary and secondary biomass resources, final energy
  - New calibration

- Further research
  - Refining BAU scenario
    - Introduction of current bioenergy policy trends
  - Detailing wood pellet consumption technology in residential and commercial sector
  - Links to water consumption
Thank you
## Commerce des bioénergies

### Granulés de bois
- La biomasse la plus commercialisée
- Europe (1er producteur ; 3-4 millions tonnes et 37% exporté), USA et Canada (2nd producteurs ; 2 millions)

### Bioéthanol
- USA et Brésil (90% de la production globale, environ 40 millions m3)
- Brésil (le plus grand exportateur, 48% du marché global), USA (6%) et France (6%)

### Résidus agricoles
- UK, Pays-Bas et Italie; co-combustion avec le charbon

### Huile végétale
- Indonésie et Malaisie : les plus grands producteurs et exportateurs d’huile de palme
- Argentine : l’huile de soja

### Commerce des bioénergies (2011-2012)

<table>
<thead>
<tr>
<th>Biofuel Type</th>
<th>Trade Volume</th>
<th>Base Year</th>
<th>Main Trader</th>
<th>Source</th>
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<td>Bioethanol</td>
<td>127 PJ</td>
<td>2011</td>
<td>Brazil, China, USA, Europe, Japan</td>
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<td>Biodiesel</td>
<td>88 PJ</td>
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<td>Argentina, USA, Malaysia, Indonesia</td>
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<tr>
<td>Wood pellets</td>
<td>167 PJ</td>
<td>2012</td>
<td>Europe, Canada, USA</td>
<td>M.Junginger et al. , FAOSTAT</td>
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<tr>
<td>Fuelwood</td>
<td>82 PJ</td>
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<td>Europe, Southern Africa, Canada, USA</td>
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<td>Charcoal</td>
<td>20 PJ</td>
<td>2006</td>
<td>N/A</td>
<td>IEA</td>
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<td>Vegetable oils and seeds</td>
<td>&gt;60 PJ</td>
<td>2006</td>
<td>EU, Argentina, Malaysia, Indonesia</td>
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<td>Industrial roundwood</td>
<td>1165 PJ</td>
<td>2011</td>
<td>Europe, China, India, Canada, Malaysia</td>
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<td>Wood chips and particles</td>
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<td>Indirect trade</td>
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<td>Total</td>
<td>2974 PJ</td>
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</table>

Source : Junginger and Faaij 2008
2.1. Estimation du potentiel de la bioénergie

- **Paramètres économiques (commodités agricoles)**
  - Base de données : OECD-FAO Agricultural Outlook 2015-2024
  - Ré-estimation du coût par hectare, commodité, région

- **Paramètres économiques (commodités forestières)**
  - Base de données : Outlook to 2060 for World Forests and Forest Industries, USDA
  - Moyenne des valeurs à l'exportation du bois de chauffage et du bois industriel

- **Paramètres économiques (Résidus)**

- **D’autres paramètres**
  - Taux de conversion en matière sèche et Contenu énergétique
    - Commodités agricoles
      (Energy research Centre of the Netherlands, Phyllis2 - Database for biomass and waste, https://www.ecn.nl/phyllis2/)
    - BCEF (Biomass conversion and expansion factor) par région
      (Forest resource assessment 2015 – FRA, FAO)
    - Contenu énergétique de biomasse solide (exclu. Cultures) : 18.3MJ/kgDM,
2.1. Estimation du potentiel de la bioénergie

Comparaison avec le modèle TIAM-FR

- TIAM-FR : 217.4 EJ en 2050 vs Nouveau : 469.6 EJ en 2050

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<tr>
<th>Region</th>
<th>Biomasse solide</th>
<th>Culture Énergétique</th>
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