# MEETING ENERGY DEMAND IN BRAZIL WITH BIOENERGY

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**COURSE: ESTIMATING SUSTAINABILITY**

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## 1. Questions

i. How much energy can be generated in each year (2007 -2016) if all the feedstock crops (corn, sugarcane, palm oil, soybean, and rapeseed) produced by Brazil are used to produce Ethanol and Biodiesel which is used for energy (KWh) generation with different budget restrictions on cost of producing biofuel from crops?

$$Max \quad E = \sum_{j,f,t} \left(a_{j,f,t} \bullet X_{j,f,t}\right) \tag{1}$$

$s.t.$

$$b_{i,j,t} \bullet \sum_{f} X_{j,f,t} \leq m_{i,j,t} \quad \forall\, i,j,t \tag{2}$$

$$\sum_{j,f} \left(p_{j,f,t} \bullet X_{j,f,t}\right) \leq \sum_{j} v_{j,t} \quad \forall\, t \tag{3}$$

ii. How much land will be required meet the energy demand from each sector using bioenergy crop under a specific $CO_2$ emission limit.

$$Min \quad L = \sum_{j,f,t} \left(b_{"land",j,t} \bullet X_{j,f,t}\right) \tag{4}$$

$s.t.$

$$\sum_{j,f} \left(a_{j,f,t} \bullet X_{j,f,t}\right) \geq \sum_{s} d_{s,t} \quad \forall\, t \tag{5}$$

$$\sum_{f,j} \left(g_{c,f,j,t} \bullet X_{j,f,t}\right) \leq h_{c,t} \quad \forall\, c,t \tag{6}$$

$$\sum_{j,f} \left(p_{j,f,t} \bullet X_{j,f,t}\right) \leq \sum_{j} v_{j,t} \quad \forall\, t \tag{7}$$

## 1. Data/Model Inputs

i. *m* (*i, j, t*) Area cultivated for each crop (millha)[1].
ii. Biofuel yield from crop (litre/millha) [2][3].
iii. *a* (*j, f, t*) Energy generated from biofuel (GWh/mill ha)[4].
iv. *g* (*c, f, j, t*) Emission coefficient of Biofuel in Mton $CO_2$/millha[4].
v. *p* (*j, f, t*) Cost of producing Biofuel from crop (US$/millha)[5]
vi. *h* (*c, t*) $CO_2$ emission from Energy sector in Brazil as of 2007[6].
vii. *d* (*s, t*) Energy demand by different sectors[7]
viii. *b* (*i, j, t*) resource requirement. 1 and 0.5 for annual and biennial crop respectively.

## 2. Assumptions

i. Biofuel yield from crop increases by 4% annually due to increasing efficiency of production.
ii. $CO_2$ emission from energy sector decreases by 9% annually.

## 3. GAMS code

**Question 1;**

```
Sets
```

```
allitem
 /maize,sugarcane,oilpalm,soybean,rapeseed,
  land,
  co2,
  biodiesel,ethanol,
  industry,transport,residential,commercial,agriculture,
  2007*2016/
j(allitem)  Crop
 /maize,sugarcane,oilpalm,soybean,rapeseed/
i(allitem)  Resources: land in millha
 /land/
s(allitem)  Energy Demand
 /industry,transport,residential,commercial,agriculture/
f(allitem)  Biofuel type (in litres)
 /biodiesel,ethanol/
t(allitem)  Period
 /2007*2016/
c(allitem)  Emission
 /co2/
;
$include data.gms

parameter b(i,j,t) land requirement for crop. Assumption that
oilpalm is biennial;
          b(i,j,t) = 1 ;
          b(i,"oilpalm",t) = 0.5;
parameter v(j,t) Budget of biofuel production in million US$ ;
          v(j,t) = 'budget';
parameter p(j,f,t);
          p(j,f,t) = pp(j,f,t)/1000000;

FREE VARIABLE E 'energy generated (GWh)';
NONNEGATIVE VARIABLE X(j,f,t);

Equations
Energy           'defined objective function'
Resource(i,j,t)   'land-use restriction for crop cultivation for
each period'
cost_Equ(t)
;
Energy..  E  =E= SUM((j,f,t),a(j,f,t)*X(j,f,t));

Resource(i,j,t).. b(i,j,t)*SUM(f,X(j,f,t))=L= m(i,j,t);

cost_Equ(t)..
 SUM((j,f),p(j,f,t)*X(j,f,t))=L= SUM(j,v(j,t));

Model bioenergy / all /  ;
Solve bioenergy using LP maximizing E;
display X.l, X.m;
```

**Question 2;**

```
Sets
allitem
 /maize,sugarcane,oilpalm,soybean,rapeseed,
  land,
```

```
  co2,
  biodiesel,ethanol,
  industry,transport,residential,commercial,agriculture,
  2007*2016/
j(allitem)  Crop
 /maize,sugarcane,oilpalm,soybean,rapeseed/
i(allitem)  Resources
 /land/
s(allitem)  Energy Demand
 /industry,transport,residential,commercial,agriculture/
f(allitem)  Biofuel type
 /biodiesel,ethanol/
t(allitem)  Period
 /2007*2016/
c(allitem)  Emission
 /co2/
;
$include data.gms

parameter b(i,j,t) land requirement for crop;
          b(i,j,t) = 1 ;
          b(i,"oilpalm",t) = 0.5;
parameter h(c,t) emission in Megatonne;
          h(c,t) = hh(c,t)/1000000;
parameter g(c,f,j,t) Emission in Mtoe C02 per millha;
          g(c,f,j,t) = gg(c,f,j,t)/1000000          ;
parameter v(j,t);
          v(j,t) = 'budget constraint;
parameter p(j,f,t);
          p(j,f,t) = pp(j,f,t)/1000000;

FREE VARIABLE L;
NONNEGATIVE VARIABLE X(j,f,t);

Equations
Objective_Equ
Energy_demand_Equ(t)
Emission_Equ(c,t) co2 emission limit
cost_Equ(t) cost restriction
;
Objective_Equ..
 L=E=SUM((j,f,t),b("land",j,t)*X(j,f,t));
Energy_demand_Equ(t)..
 SUM((j,f),a(j,f,t)*X(j,f,t))=G= SUM(s,d(s,t));

Emission_Equ(c,t)..
 SUM((f,j),g(c,f,j,t)*X(j,f,t))=L= h(c,t);
cost_Equ(t)..
 SUM((j,f),p(j,f,t)*X(j,f,t))=L= SUM(j,v(j,t));

Model energy / all /
Solve energy using LP minimizing L;
Display X.l, X.m;
```

## 4. Model Results

Table 1. Land Harvested for bioenergy production under budget constraints

| **Crop.fuel** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **Budget millUS$** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| sugarcane.ethanol | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 | 1 |
| sugarcane.ethanol | 0.063 | 0.06 | 0.058 | 0.056 | 0.054 | 0.052 | 0.05 | 0.048 | 0.046 | 0.044 | 20 |
| sugarcane.ethanol | 0.09 | 0.086 | 0.083 | 0.08 | 0.077 | 0.074 | 0.071 | 0.068 | 0.065 | 0.063 | 50 |
| sugarcane.ethanol | 0.239 | 0.23 | 0.221 | 0.212 | 0.204 | 0.196 | 0.189 | 0.182 | 0.175 | 0.168 | 80 |
| sugarcane.ethanol | 0.358 | 0.344 | 0.331 | 0.319 | 0.306 | 0.294 | 0.283 | 0.272 | 0.262 | 0.252 | 120 |
| sugarcane.ethanol | 0.597 | 0.574 | 0.552 | 0.531 | 0.51 | 0.491 | 0.472 | 0.454 | 0.436 | 0.42 | 200 |
| sugarcane.ethanol | 0.896 | 0.861 | 0.828 | 0.796 | 0.766 | 0.736 | 0.708 | 0.681 | 0.654 | 0.629 | 300 |
| sugarcane.ethanol | 1.791 | 1.722 | 1.656 | 1.593 | 1.531 | 1.472 | 1.416 | 1.361 | 1.309 | 1.259 | 600 |
| sugarcane.ethanol | 3.583 | 3.445 | 3.312 | 3.185 | 3.063 | 2.945 | 2.831 | 2.723 | 2.618 | 2.517 | 1200 |
| sugarcane.ethanol | 7.081 | 6.89 | 6.625 | 6.37 | 6.125 | 5.89 | 5.663 | 5.445 | 5.236 | 5.034 | 2400 |
| oilpalm.biodiesel | 0.053 | | | | | | | | | | 2400 |
| maize.biodiesel | 10.867 | | | | | | | | | | 4800 |
| maize.ethanol | 2.9 | 1.8 | 0.542 | | | | | | | | 4800 |
| sugarcane.ethanol | 7.081 | 8.14 | 8.618 | 9.077 | 9.601 | 9.705 | 10.195 | 10.42 | 10.111 | 10.069 | 4800 |
| oilpalm.biodiesel | 0.204 | 0.206 | 0.208 | 0.213 | 0.218 | 0.226 | 0.217 | 0.253 | 0.224 | | 4800 |
| soybean.biodiesel | 20.565 | 21.246 | 21.75 | 18.888 | 13.069 | 9.723 | 4.444 | 0.362 | | | 4800 |
| maize.ethanol | 13.767 | 14.445 | 13.655 | 12.679 | 11.83 | 10.414 | 8.243 | 6.446 | 5.406 | 4.147 | 9600 |
| sugarcane.ethanol | 7.081 | 8.14 | 8.618 | 9.077 | 9.601 | 9.705 | 10.195 | 10.42 | 10.111 | 10.223 | 9600 |
| oilpalm.biodiesel | 0.204 | 0.206 | 0.208 | 0.213 | 0.218 | 0.226 | 0.217 | 0.253 | 0.28 | 0.284 | 9600 |
| soybean.biodiesel | 20.565 | 21.246 | 21.75 | 23.327 | 23.969 | 24.975 | 27.907 | 30.274 | 32.181 | 33.183 | 9600 |
| rapeseed.biodiesel | 0.032 | 0.033 | 0.031 | 0.046 | | | | | | | 9600 |
| maize.ethanol | 13.767 | 14.445 | 13.655 | 12.679 | 13.219 | 14.198 | 15.28 | 15.433 | 15.407 | 14.959 | 19200 |
| sugarcane.ethanol | 7.081 | 8.14 | 8.618 | 9.077 | 9.601 | 9.705 | 10.195 | 10.42 | 10.111 | 10.223 | 19200 |
| oilpalm.biodiesel | 0.204 | 0.206 | 0.208 | 0.213 | 0.218 | 0.226 | 0.217 | 0.253 | 0.28 | 0.284 | 19200 |
| soybean.biodiesel | 20.565 | 21.246 | 21.75 | 23.327 | 23.969 | 24.975 | 27.907 | 30.274 | 32.181 | 33.183 | 19200 |
| rapeseed.biodiesel | 0.032 | 0.033 | 0.031 | 0.046 | 0.042 | 0.046 | 0.045 | 0.044 | 0.048 | 0.048 | 19200 |
| maize.ethanol | 13.767 | 14.445 | 13.655 | 12.679 | 13.219 | 14.198 | 15.28 | 15.433 | 15.407 | 14.959 | 29200 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| sugarcane.ethanol | 7.081 | 8.14 | 8.618 | 9.077 | 9.601 | 9.705 | 10.195 | 10.42 | 10.111 | 10.223 | 29200 |
| oilpalm.biodiesel | 0.204 | 0.206 | 0.208 | 0.213 | 0.218 | 0.226 | 0.217 | 0.253 | 0.28 | 0.284 | 29200 |
| soybean.biodiesel | 20.565 | 21.246 | 21.75 | 23.327 | 23.969 | 24.975 | 27.907 | 30.274 | 32.181 | 33.183 | 29200 |
| rapeseed.biodiesel | 0.032 | 0.033 | 0.031 | 0.046 | 0.042 | 0.046 | 0.045 | 0.044 | 0.048 | 0.048 | 29200 |

Table 2. Cumulative Land Harvested for bioenergy production under budget costraints

| Budget Contraint (mill US$) | Sugarcane (millha) | Oilpalm (millha) | Maize (millha) | Soybean (millha) | Rapeseed (millha) |
|---|---|---|---|---|---|
| 1 | 0.025 | | | | |
| 20 | 0.531 | | | | |
| 50 | 0.757 | | | | |
| 80 | 2.016 | | | | |
| 120 | 3.021 | | | | |
| 200 | 5.037 | | | | |
| 300 | 7.555 | | | | |
| 600 | 15.11 | | | | |
| 1200 | 30.222 | | | | |
| 2400 | 60.359 | 0.053 | | | |
| 4800 | 93.017 | 1.969 | 16.109 | 110.05 | |
| 9600 | 93.171 | 2.309 | 101.03 | 259.38 | 0.142 |
| 19200 | 259.377 | 2.309 | 143.04 | 93.171 | 0.415 |
| 29200 | 259.377 | 2.309 | 143.04 | 93.171 | 0.415 |

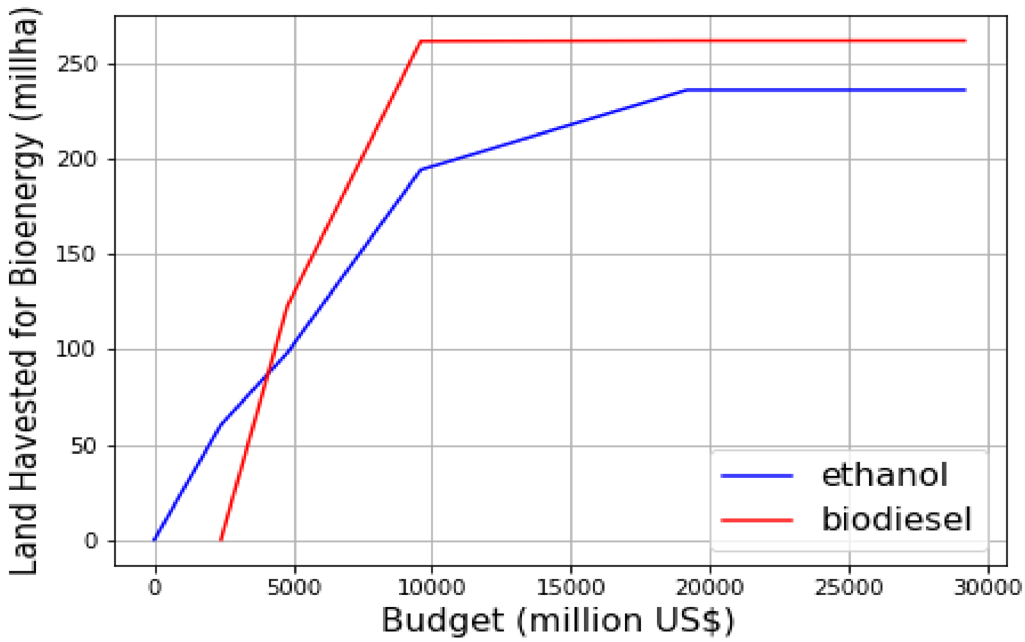


Figure 1. Cummulative biofuel production

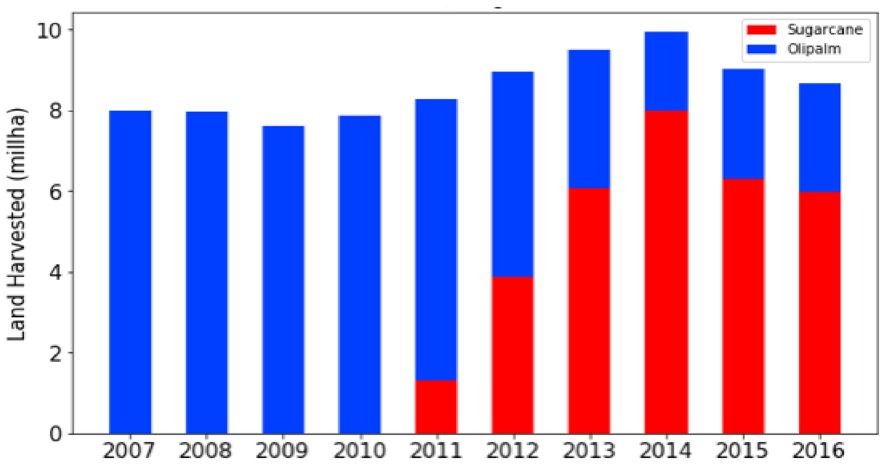


Figure 2. Bioenergy production under a $ 4.9 Billion Constraint.

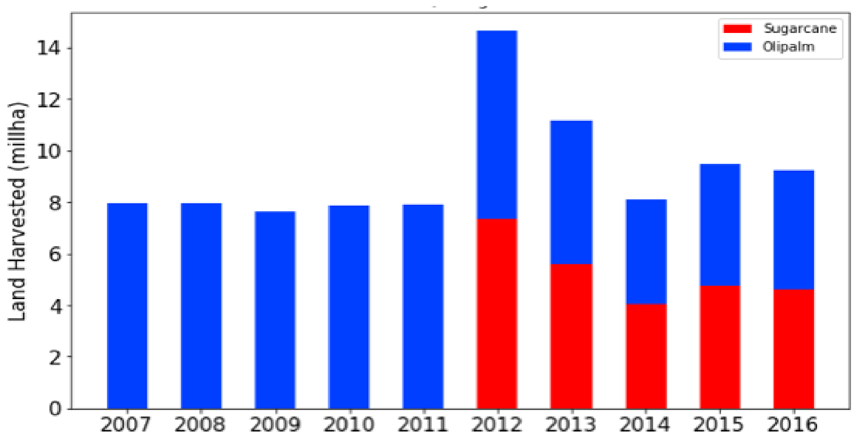


Figure 3. Bioenergy production under a $ 5.1 Billion Constraint.

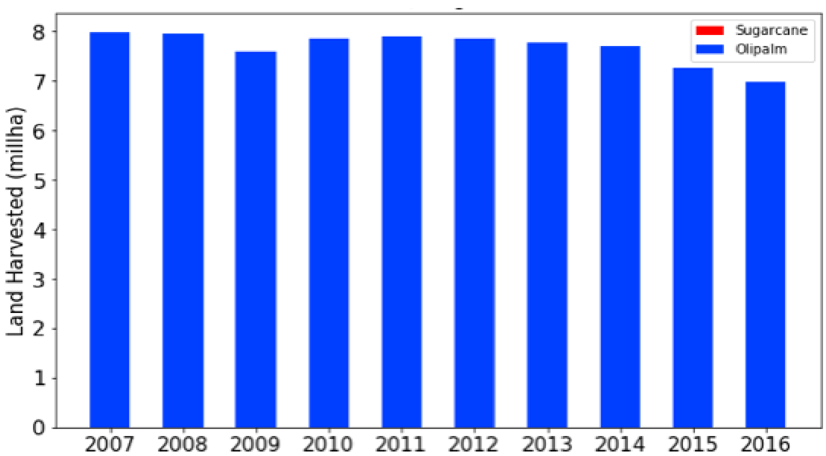


Figure 4. Bioenergy production under a $ 5.5 Billion Constraint.

Table 1. shows the amount of land harvested for bioenergy production annually under different cost of production constraints, under very small budget, only ethanol is produced from sugarcane, until the budget reaches $2.4 billion than biodiesel production from oilpalm. A cost constraints of $19.2 billion is required to produce fully convert all the energy crop to biofuel. Rapeseed is the least cost effective as it is the least produced (table 2). At low budget, all the

production of bioenergy comes from ethanol up till a $2.4 billion budget then bioenergy from biodiesel begins, at about $8 billion budget, bioenergy production from biodiesel overtakes production from ethanol.

Below a approximately $4.9 Billion constraint Brazil cannot meet her energy demand with Bioenergy because sufficient ethanol and biodiesel cannot be produced under such constraint for any given period. At a $4.9 Billion budget, sufficient biodiesel can be produced from oilpalm to meet the annual energy demand from 2007 to 2010 by harvesting approximately 8 million hectares of oilpalm. In 2011, the cost of production of sufficient biodiesel form oilpalm exceeds the available budget hence, there is need to diversify biofuel production. A fraction of production goes into ethanol from sugar cane, about 1 millha is required to produce sufficient ethanol compliment the biodiesel from oilpalm, this is due to the high ethanol yield of sugarcane and low cost of production. Production of ethanol from sugarcane continues to increase while production of biodiesel from oilpalm reduces from 2011 till 2014 where a reversal occurs i.e production of ethanol decreases while biodiesel reduces. The overall production reduces despite increase in energy demand due to the 4% annual increase in efficiency of biofuel production.

At a $5.1 billion constraints sufficient biodiesel is produced from about 8 millha of oilpalm, this is sufficient to meet the energy annual demand from 2007 to 2011, from 2012, sufficient biofuel cannot be produced from oilpalm under this cost constraint hence about 50% of total production goes into ethanol production from sugarcane. Under a $5.5 billion constraint, sufficient biodiesel can be produced from oilpalm to meet the energy demand throughout the period of interest without additional production from other crops.

## References

[1] https://www.iea.org/statistics

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[3] Kuss, V.V.; Kuss, A.V.; da Rosa, R.G.; Aranda, D.A.G.; Cruz, Y.R.(2015) Potential of biodiesel production from palm oil at Brazilian Amazon. Renew. Sustain. Energy Rev. 2015, 50, 1013–1020.

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[5] EIA. 2006. Annual energy review 2005. DOE/EIA-0384(2006) Washington D.C.: U.S. Department of Energy, Energy Information Administration

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