Interaction between Energy and Agriculture via Biofuels and Future Social Impact

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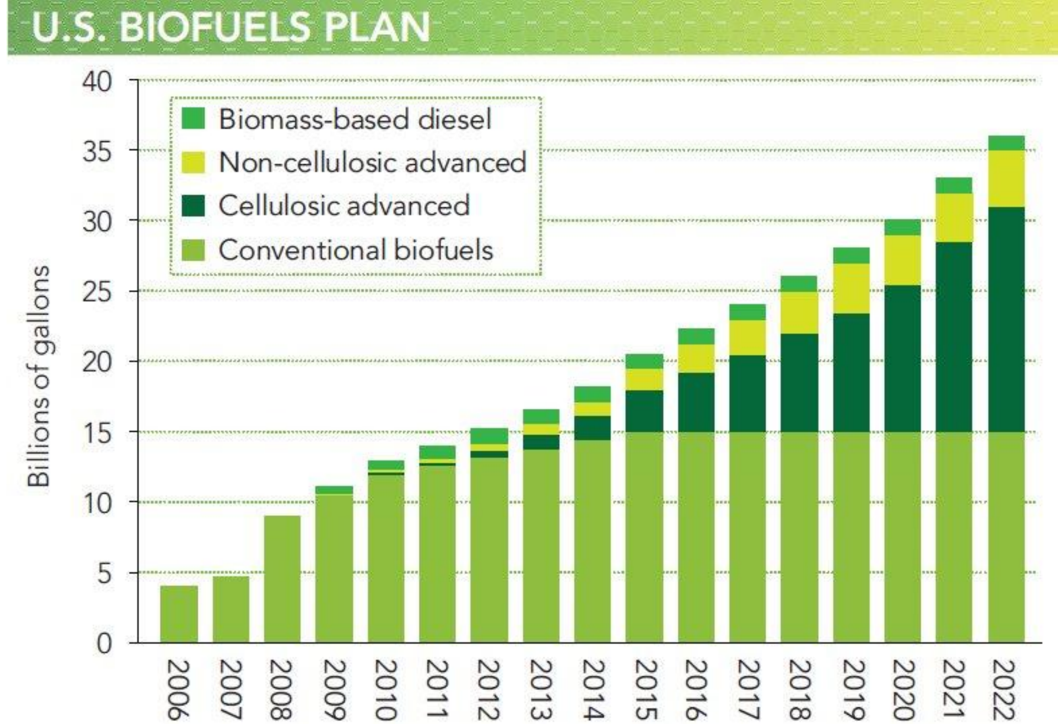
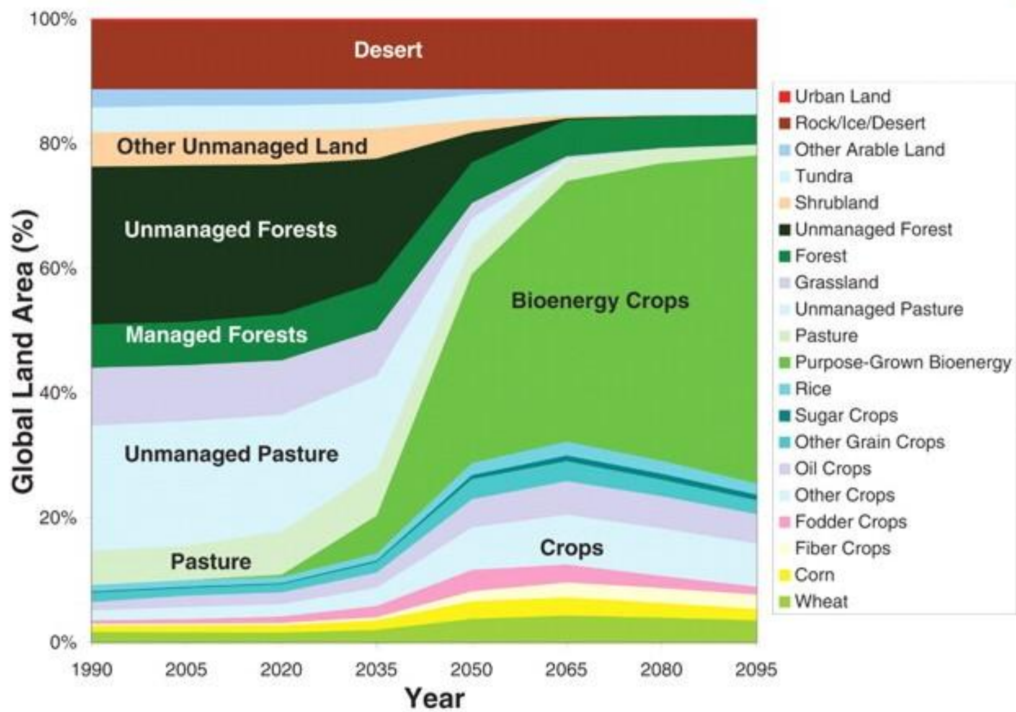
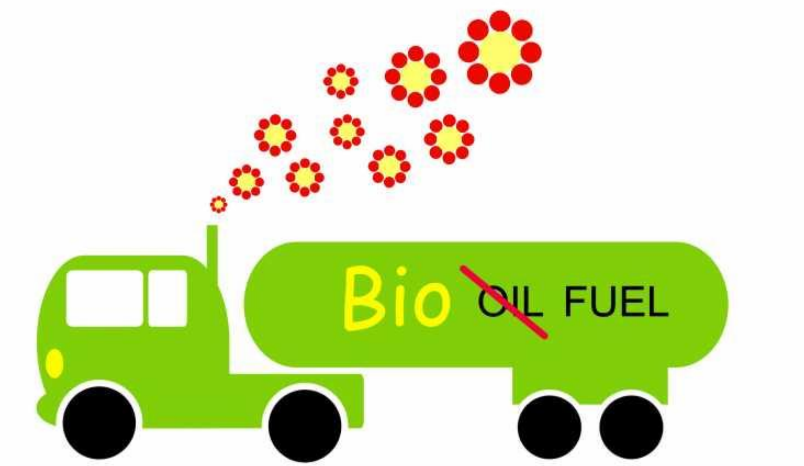

U.S. BIOFUELS PLAN
Biomass-based diesel
Non-cellulosic advanced
Cellulosic advanced
Conventional biofuels
Billions of gallons
0
5
10
15
20
25
30
35
40
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022


Desert
Other Unmanaged Land
Unmanaged Forests
Managed Forests
Unmanaged Pasture
Pasture
Bioenergy Crops
Crops
Global Land Area (%)
0%
20%
40%
60%
80%
100%
1990
2005
2020
2035
2050
2065
2080
2095
Year
Urban Land
Rock/Ice/Desert
Other Arable Land
Tundra
Shrubland
Unmanaged Forest
Forest
Grassland
Unmanaged Pasture
Pasture
Purpose-Grown Bioenergy
Rice
Sugar Crops
Other Grain Crops
Oil Crops
Other Crops
Fodder Crops
Fiber Crops
Corn
Wheat

erda


Bio
OIL
FUEL

Abstract

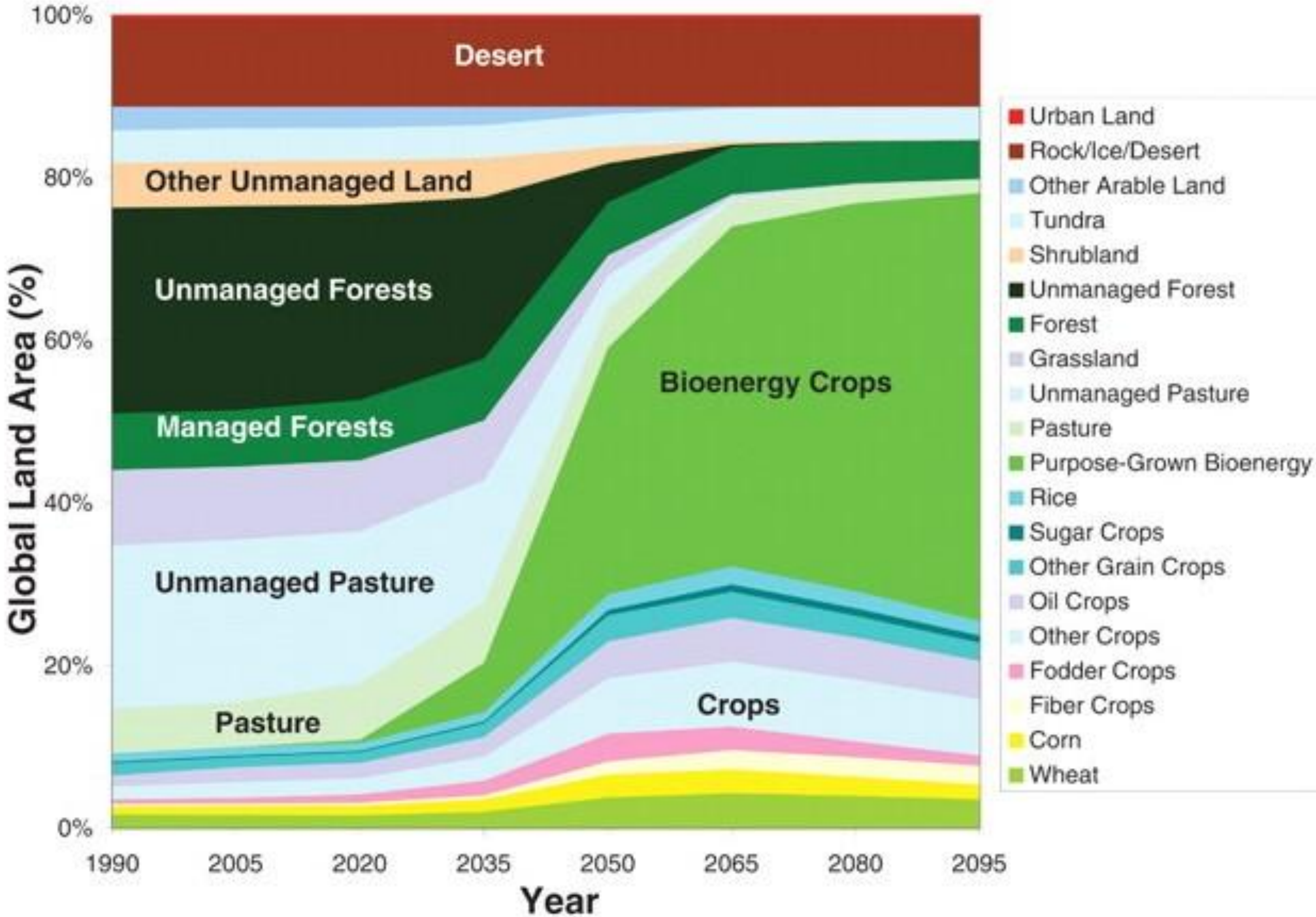
- The competition between agriculture and biofuels has important consequences for future security of supply of both food and energy. At this moment, practically all arable land is already used, and it has to be split between food production and substitutes of oil.
- While there exist alternative solutions for the future global energy scarcity, that are related to use such sources and solar and wind energy, we are not aware about possible technologies to substitute oil by renewable energies in transportation (apart from rail transport driven by electricity that can be produced by renewables), especially in air transport. That is why our focus will be on future matching of demand and supply for food and transportation.
- Biofuels emerge before oil peak, when marginal cost of oil extraction starts to exceed the cost of agricultural production. Later we consider more complex model that also involves water, both for producing agriculture and biofuels, and for direct consumption. We also add forest and positive dependence between forested area and global water supply.

Introduction

- We will start our analysis with a simple model, where total arable land is fixed and is decomposed between land, used for agriculture, and for biofuel growing. As for oil supply, we assume a kind Hubbert-type curve, given by exogenous function with one peak (oil-peak). We also will assume both exponential population growth, along with exponential growth of agricultural productivity.
- The equilibrium for a simple model consists from the dynamics of food and energy prices in the environment of growing population and agricultural productivity.
- There exist also complementary problems, related to deforestation and future water scarcity (locally even for personal needs, but globally for agriculture). Since there exists a positive correlation between the global area covered by forest, on one hand, and global supply of fresh water, on the other, we assumed some functional dependence between both variables.

Motivation

- The present model is highly stylized, but tries to capture interaction between different natural and economic factors: energy transition, land use dynamics, water scarcity.
- There exist some forecasts about future land use in the 21st century (see next slide). [1] argues that carbon tax only on fossil fuel can transform land use, so that about its half can be used for biofuel, and forest share drops to 5%. But if we consider oil peak (present reserves are only for 40 years, and we need to replace gasoline in transportation) driving substitution of oil with biofuels, the result will be the same.
- [2] attracts attention to water scarcity problem that may come earlier than global warming. Currently agriculture consumes lion share of water resources in many countries, and biofuels will increase this pressure.
- But what other processes will accompany such change in land use? First, this paper focuses on relative cost of food and energy. Second, it argues about the link between forest endowment and water scarcity.



Source: [1,2], http://theresilientearth.com/?q=content/watering-down-biofuels

Simple Model. Assumptions 1.

- Consider closed (global) economy with two goods, food and energy. Food is produced using agricultural land, L_A , with technological development,

  $$Y_A(t) = L_A(t)\, e^{ct}.$$

- Energy has two modes of production: non-renewable, with global (oil) supply described by Hubbert curve,

  $$Y_0(t) = (t+T)K\, e^{-\mu t}.$$

  where T stands for the current moment, measures its relative position to oil peak, and biofuels, that are produced using land, L_B , with growing technology of its development:

  $$Y_B(t) = L_B(t)\, e^{ct}.$$

- The total land endowment is normalized to one: $L_A(t) + L_B(t) = 1$.

Simple Model. Assumptions 2.

- There is also exogeneous exponential population growth with power γ:

  $$N(t)=N(0)e^{\gamma t}.$$

  Initially we assume that exponents coincide, c= γ , but can depart from this assumption in future. Estimations: c=0.25% [1], γ now is higher but slows down.

- Every agent has the preferences for food and energy, given by:

  $$U(F,E)=\ln(F)+\ln(E).$$

- He is endowed with Z units of money in each period, that are spend for those goods, given their prices. The budget constraint is:

  $$p_F F + p_E E = Z.$$

Individual Optimization

Consider the Lagrangian

$$L = \ln F + \ln E + \lambda(Z - p_F F - p_E E).$$

The first order conditions are:

$$\lambda p_F F = \lambda p_E E = 1, \qquad p_F F + p_E E = Z.$$

Solving, the system, we get:

$$F = \frac{Z}{2p_F}, \qquad E = \frac{Z}{2p_E}, \qquad \lambda = \frac{2}{Z}.$$

Market Equilibrium.1

All equilibrium conditions depend on time t in a parametric way. The food market equilibrium is:

$$\frac{Z}{2p_F}N(0)e^{\gamma t} = L_A(t)e^{ct}. \tag{11}$$

The energy market equilibrium is:

$$\frac{Z}{2p_E}N(0)e^{\gamma t} = L_B(t)e^{ct} + (t+T)Ke^{-\mu t}. \tag{12}$$

Land market equilibrium is:

$$L_A + L_B = 1. \tag{13}$$

Market Equilibrium.2

- We consider no-arbitrage opportunity. Suppose that land owners receive some rent R(t) per unit of land and that oil extraction requires some cost C(t). Historically, we had the period of only oil and no biofuels. This means that oil extraction cost was cheaper than corresponding production of biofuels. We also may assume heterogeneous extraction cost across location, with the price equal to marginal cost. Since the land output grows exponentially, so does the rent: $R(t)=R(0)e^{ct}$.
- When $C(t)<R(t)$, it is cheaper to extract oil, than to produce biofuel.
- The marginal cost of oil extraction will now determine energy price. But this works both ways: the most expensive oil fields may simply not be exploited, and then the residual amount of oil (from Hubbert's curve) will be available at food price.
- For our equal preferences, in the limit half land will produce food, and half – biofuel. (In reality preferences may differ giving other ratio).

Market Equilibrum. 3

Now we can solve for agricultural equilibrium for $t < 0$:

$$t < 0 \qquad L_A(t) = 1, \qquad p_F(t) = e^{(\gamma - c)t} Z N(0)/2.$$

Now consider energy equilibrium for $t < 0$.

$$t < 0 \qquad L_B(t) = 0, \qquad p_F(t) = e^{(\gamma + \mu)t} \frac{ZN(0)}{2(t+T)K}.$$

When oil extraction cost exceeds agricultural rent, it becomes profitable to allocate some land for biofuel production. Since we need to produce $F=E$, the dynamics of land for agriculture and biofuels will be as follows:

$$L_A(t) = \frac{1}{2} + \frac{t+T}{2} K e^{-(\mu + c)t},$$
$$L_B(t) = \frac{1}{2} - \frac{t+T}{2} K e^{-(\mu + c)t}.$$

Three Goods Model

- Now we add forest and water, making forested land a part of global land endowment.
- We also assume that water supply in a positive function of forested area.
- Production technologies will also include water. For simplicity, Leontieff production function in land and water is assumed for both agriculture and biofuels.
- Preferences now also include individual water consumption.

$$U(F, E) = \ln(F) + \ln(E) + h \ln(W_i).$$

Market balance for water is given by:

$$W(L_f)(t) \geq N(t)W_i(t) + W_A(t) + W_B(t)$$

Water in Not Yet Scarce

It is assumed that initially half of land (total endowment now normalized by 2) is occupied by forest.

Microeconomic optimization will give now:

$$\lambda p_F F = \lambda p_E E = \lambda p_W W/h = 1, \qquad p_F F + p_E E + p_W W = Z. \Rightarrow$$

$$\lambda = \frac{2+h}{Z}, \quad W = \frac{hZ}{(2+h)p_W}, \quad F = \frac{Z}{(2+h)p_F}, \quad E = \frac{Z}{(2+h)p_E}.$$

Consider now the equilibrium. Initial water supply $W_s(0) = k$, because of forest endowment, but later will be $W_s(t) = k\sqrt{1 - L_A - L_B}$. The water demand is equal to arable land plus water for personal needs:

$$W_d(t) = L_A(t) + L_B(t) + N(0)e^{\gamma t}\frac{hZ}{(2+h)p_W}. \tag{25}$$

If $W_d(0) < W_s(0)$, the water is abundant, and formally can have zero price.

Water Becomes Scarse

- What are the major drivers of global market? Simple model studied the transition from the world of agriculture and fossil fuel to the world of agriculture and biofuels. Growing scarcity of oil after its peak makes it a smaller fraction of consumed energy and pushes the price of energy up to food price. If the growth of population equals to the speed of productivity growth in agriculture, then in the long run per capita endowment of both food and energy will be one half of its initial endowment at zero time, because all non-renewable energy is gone and half of the arable land have to be shifted from agricultural production to biofuels.
- What will change if we add water? In order to meet growing population demand for water, its price should grow over time. But if it is still relatively low comparing to agricultural rent (that is driven by population growth and also by growing cost of oil extraction), one may consider an expansion of arable land at the expense of forest. This will increase both food and energy production, but only until the moment when there is enough water. Full model is not elaborated in this paper.

General Policy Isssues

- The general model is only outlayed here. There are several competing processes, and the most important depends on parameter selection. If the transition from oil to biofuels will happen before water becomes scarce, then for policy issues we can use first our simple model and then simplified model with scarce water.

- If global water scarcity will coincide in time with oil scarcity, there will be complex interaction between these two processes, and it is not clear which will be dominant in what time. We also think that those processes are regional. In other words, in some regions we can observe water scarcity first, and oil scarcity will come later, while in other regions the reverse will take place. Even if oil trade is global, the water trade is not (due to high relative transport costs), and regionality will take place anyway.

Conclusions

- Two models show the temporal dynamics of static equilibria driven by substitution of non-renewable oil by biofuels. In a simple model (without water) technological progress in agriculture allows to satisfy the food demand of growing population (if both exponents of populartion growth and technological progress in agriculture are equal), but the transition from oil to biofuels requires to use half of arable land for energy production in the long run, pushing food prices up and making the utility of future consumers lower.
- The second model adds water and forest. On one hand, partial deforestation can make transition from oil to biofuels less painful (but only if water production by forest is sufficiently strong, or initial deforestation is not high). On the other hand, the major problem in future will be satisfaction of personal water demand and demand by agriculture. And it may come earlier than global warming, and possibly before oil depletion.

References

1. Marshall Wise et al. (2009) Implications of Limiting CO2 Concentrations for Land Use and Energy. Science 324, 1183
2. Hoffman Doug L. (2009) Watering down Biofuels.- The Reselient Earth, 06.08.2009; http://theresilientearth.com .

Thank you for your attention!

Please write your comments to e-mail:

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