Energy and the agroeconomic complexity of Ethiopia

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Hydroclimatic extremes under change

Project Description

Since the *Industrial Revolution*, modern agriculture has transformed from a *net energy supplier* to a *net energy user*, via extensive use of fossil fuels –that substituted solar energy inputs- and petroleum derivative products (fertilizers) (Pimentel and Pimentel 2008; Woods et al. 2010). This condenses a significant overview of *agricultural energetics*, especially for economies set on their first stage of development, growth and economic *diversification*, such as Ethiopia. Ethiopia is the *Blue Nile's* most upstream country, constituting a very sensitive hydroclimatic area. Since 2008, Ethiopian agriculture experiences a boost in energy use and agricultural value-added per worker, due to the rapid introduction of oil-fueled agricultural machinery that increased productivity and allowed crop diversification. Agriculture in Ethiopia accounts for ~82% of its total exports, ~45% of its Gross Domestic Product (GDP) and ~75% of its total labor force. In addition, Ethiopia's agricultural sector is equipped with a set of new financial tools to deal with *hydroclimatic extremes*, like the 1983-85 droughts that deteriorated its crop output, causing a devastating famine. In fact, Ethiopia's resilience from the (most) recent drought (2015-16) has been remarkable. These facts signify that Ethiopia satisfies the necessary conditions to become a regional *agritrade gravity center* in the Blue Nile, granted that the dispersion of agricultural trade comprises a primary tool for securing food supply. As *gravity equations* have been used to model global trade webs (Tinbergen 1962), similar principles may apply to agritrade as well, for identifying *emergent topological structures* and *supply chains*. By examining the relation between energy inputs in agriculture with crop diversification and value-added chains of Ethiopia's agritrade, we could extract accurate information on the importance of energy for the country's agroeconomic *complexity* and *regionalization* trend across its first stages of development. Via the use of *entropy* we may identify patterns of agritrade agglomeration or dispersal; alternatively study the continuity or fragmentation of Ethiopia's agritrade *gravity field*. Agglomeration towards Ethiopian agricultural supply would indicate the upgrade of the country's supply stability and –therefore- importance in the global agritrade web.

Keywords: Industrial Revolution, net energy, diversification, Blue Nile, hydroclimatic extremes, agritrade, gravity, value-added, complexity, regionalization, entropy

Contribution of the Project

The pattern of **large- scale energy inputs** in post-Industrial agriculture is followed by Ethiopia, as *Low Income Country* (LIC) with rapid growth of agricultural output. The impact of energy inputs on the differentiation of Ethiopia's agroeconomy is investigated as a diagnostic of an occurring **endogenous growth** process.

1. Energy, civilization and the state of global agriculture

The measure of human civilizations' evolution is the net increase in their ability to generate *physical work* and harness its *power*; both based on the universal concept of *Carnot Heat Engine*. The process of substituting labor with energy though, comes at the cost of *irreversible* depletion of natural stocks due to the *2nd Law*.

$$\eta = 1 - (T_C / T_H)$$

η = Heat Engine efficiency, $\eta \in (0,1)$

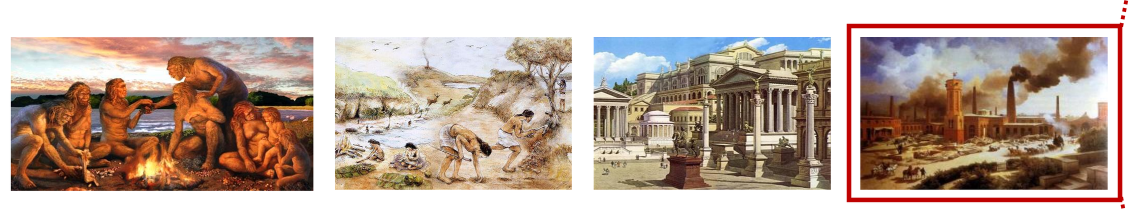
T_C = Temperature of **cold tank** (in K)

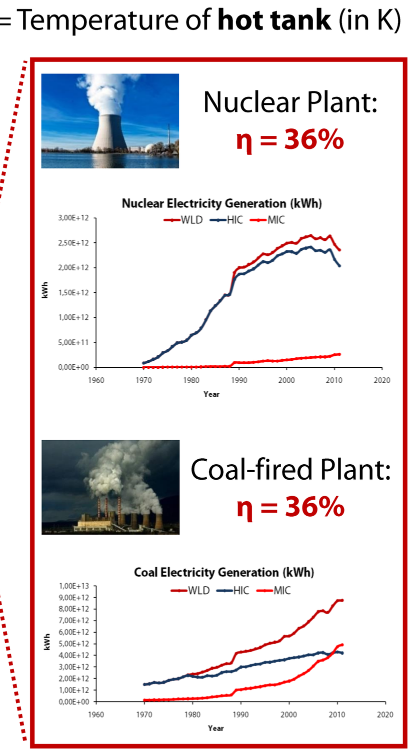
T_H = Temperature of **hot tank** (in K)

Daily energy budgets per capita (based on *Kümmel 2011*):

- ✓ Gatherers' (fruits, vegetables) Society = **2 kWh/d**
- ✓ Hunters' Society ~**3-4 kWh/d** (without fire)
- ✓ Hunters' Society ~**6 kWh/d** (with fire)

Primitive Societies (Muscle heat engines)





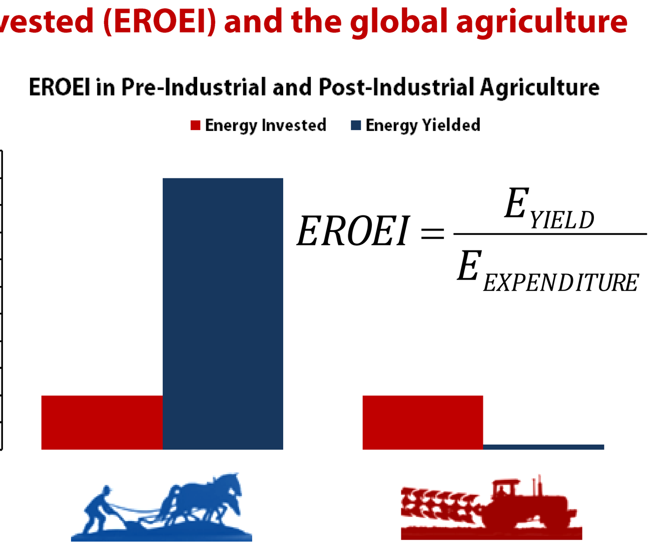
- ✓ Classical and Roman Ancestry = **20kWh/d**
- ✓ Middle Ages (1400 AC) = **30 kWh/d**
- ✓ Industrial Revolution (1850 AC) = **76 kWh/d**
- ✓ Modern Electrification Era = **112 kWh/d**

Agricultural Civilization (Biochemical solar input stocks)

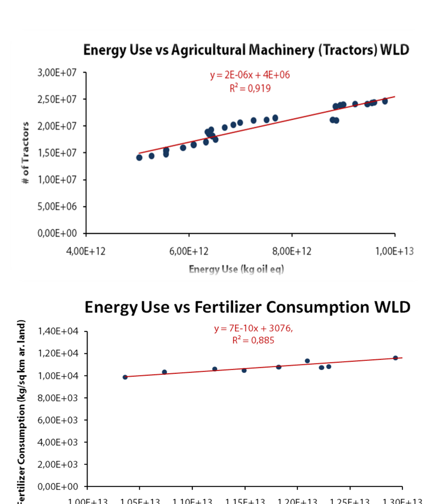
Fossil-fueled Civilization (Fossil solar input stocks)

Energy Return on Energy Invested (EROEI) and the global agriculture

In the pre-industrial era, agriculture was a net supplier of chemically stored solar energy. The *Industrial Revolution* has transformed global agriculture from a net supplier of energy to a net user of energy via the large-scale use of fossil fuels or *fossil-fuel intensive* fertilizers.



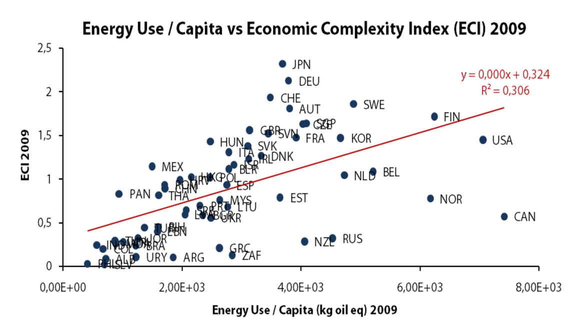
$$EROEI = \frac{E_{YIELD}}{E_{EXPENDITURE}}$$

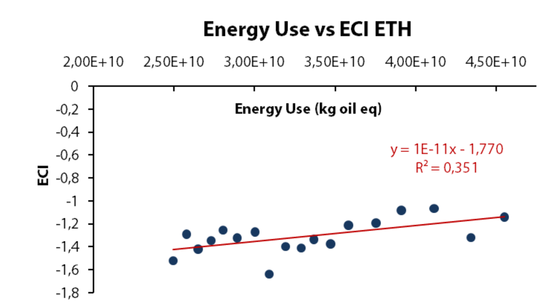


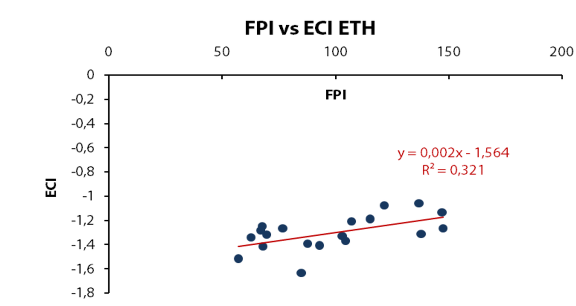
2. Energy, economic complexity and global agriculture

Energy and economic complexity

The impact of economic differentiation on economic growth is an issue primarily concerning *endogenous growth economists*. As expected, it is shown that *energy use is correlated positively to econosystems' differentiation* for the majority of countries. The analysis is based on the *Economic Complexity Index* (*ECI*) (Hausmann et al. 2011), as a measure not only of economic differentiation but of difficulty to compete to a country's output basket as well.

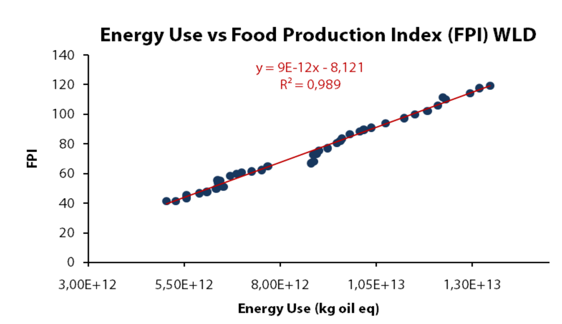


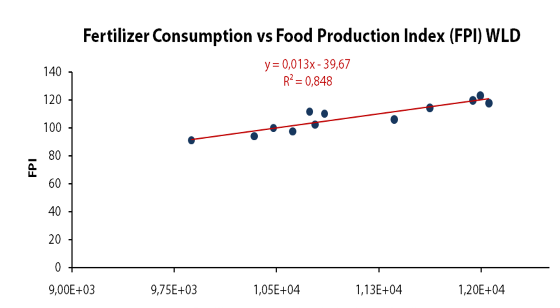


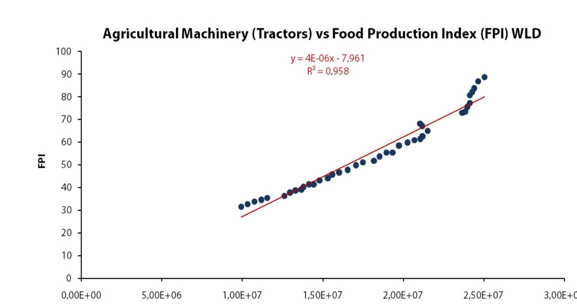


Energy and the input structure of global agriculture

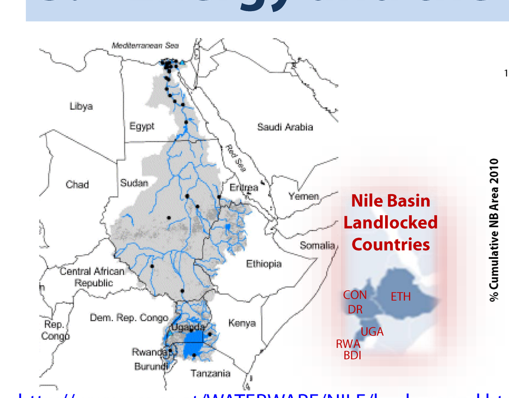
Not only *direct energy use* -as complementary to mechanical capital- is an important factor for agricultural growth and increase of the *Food Production Index* (*FPI*) -as a measure proportional to the ECI but better adapted to agriculture- but also inputs of *energy-intensive products* -as *intermediate* production factors- such as fertilizers.







3. Energy and the state of Ethiopia's agroeconomy



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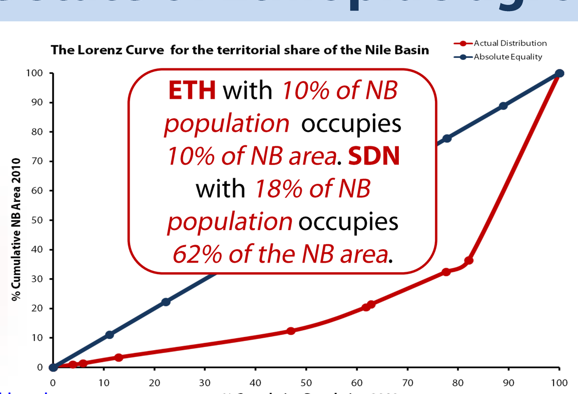
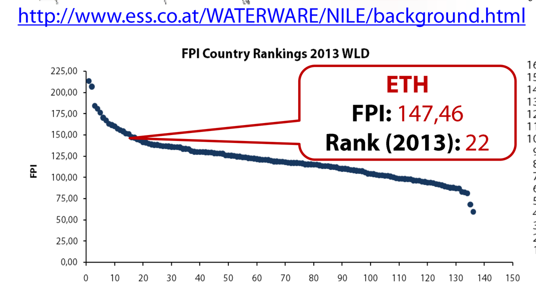
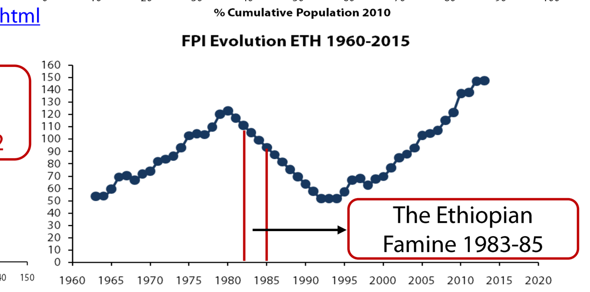


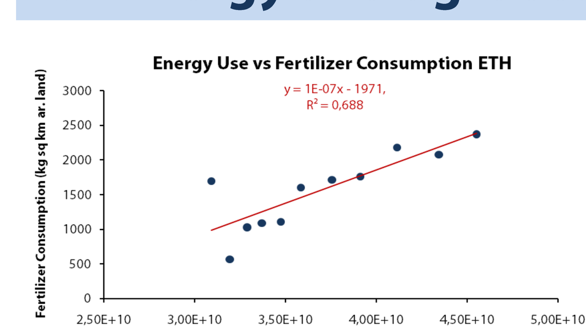




Evolution of Ethiopia's agriculture

Ethiopia (*ETH*) is a *landlocked country*, part of the *Nile Basin* (*NB*) area and the *upstream of its most important sub-area, the Blue Nile* (*BN*) that accounts for ~85% of the NB's total annual runoff. Its agricultural sector accounts for ~45% of its GDP (2013), ~82 % of exports, while occupying ~75% of its population –almost entirely *rural*. Since 1960, ETH has been rapidly *differentiating its crop output*; however the 1983-85 drought lead to the *structural collapse* of ETH's agri-sector that continued (lagged impact) for a decade. Since 1990, ETH has recovered completely.

4. Energy and agroeconomic differentiation in Ethiopia



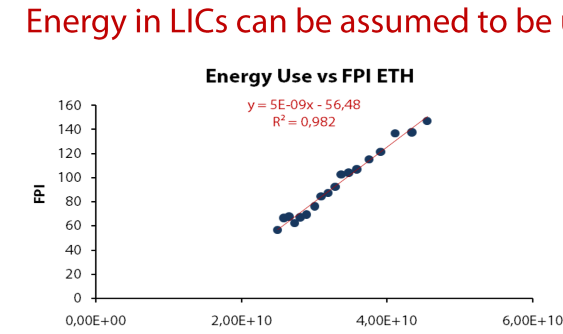
A function of agricultural differentiation for Low Income Countries (LIC)

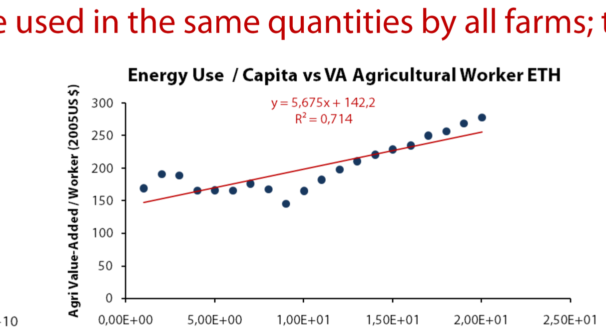
Agricultural LICs rely on *human labor* (*L*) and a *complementary production factor* (E_i) (i.e. energy); thus their growth relies mostly on the *number of products* (*N*), constituting the source of their *total income* (Y_i). The function in both its basic and logarithmic form (for linear regressions) is:

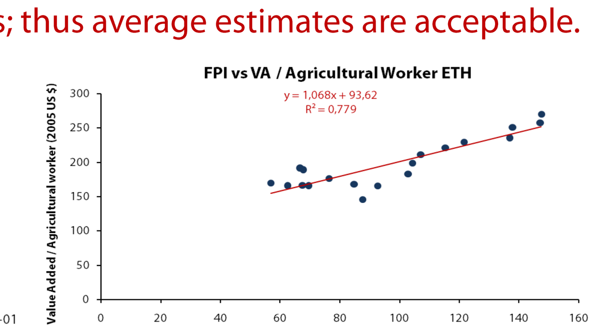
$$Y_i = L_i^{1-a} \cdot (N \cdot E_i)^a \cdot N^{1-a}$$

$$lnY_i = (1-a) \cdot (lnL_i + lnN) + a \cdot (lnE_i + lnN)$$

Energy in LICs can be assumed to be used in the same quantities by all farms; thus average estimates are acceptable.

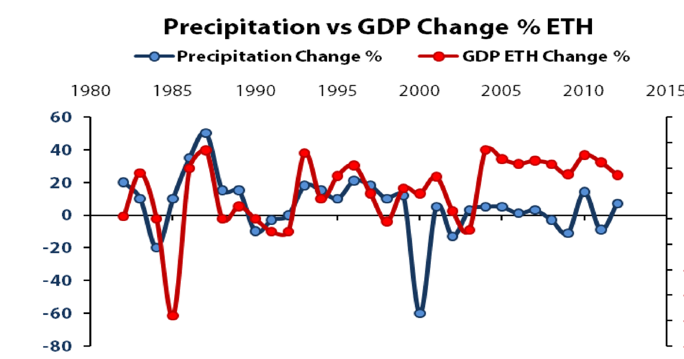


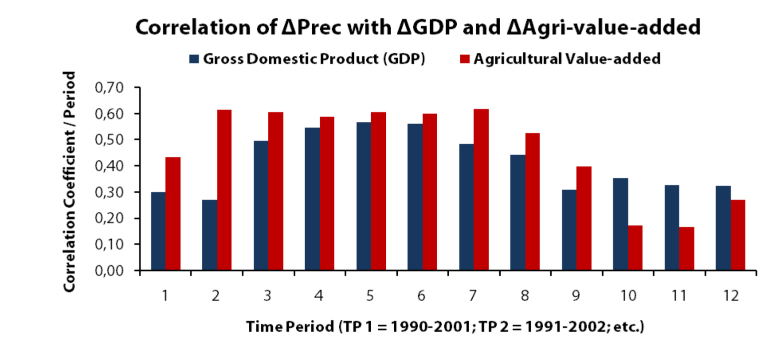




5. Hydroclimate dependence and agricultural risk in Ethiopia

Ethiopia 's economy has been heavily *depended on hydroclimate conditions*, as it applies extensively *rain-fed methods*. Its GDP is determined by agricultural value added by ~50% (1990-2012 average).

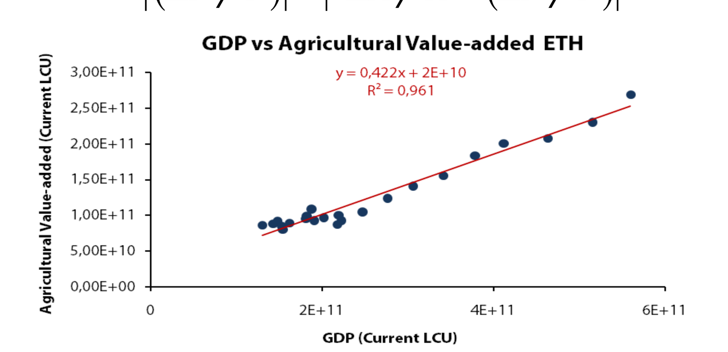


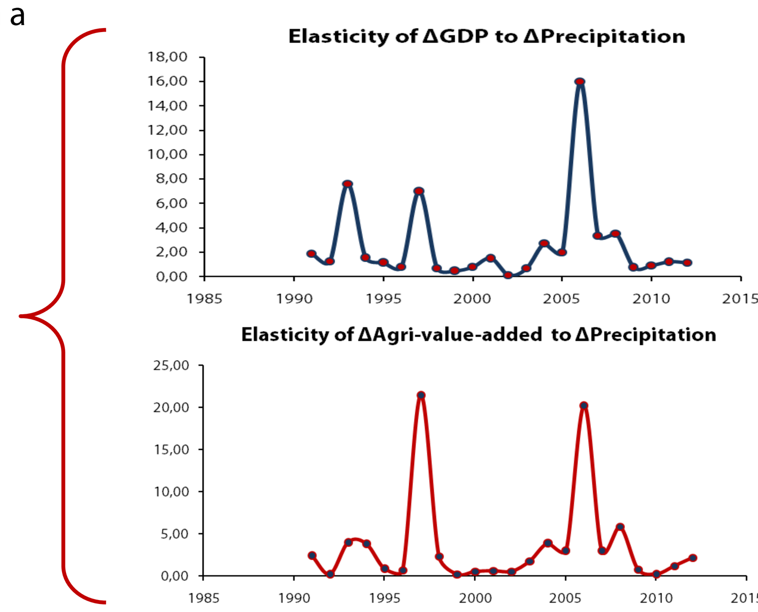


The *elasticity* (*ε*) of *GDP* (*B*) to *Precipitation* (*P*) is -via a chain rule including *Agricultural value-added* (*A*):

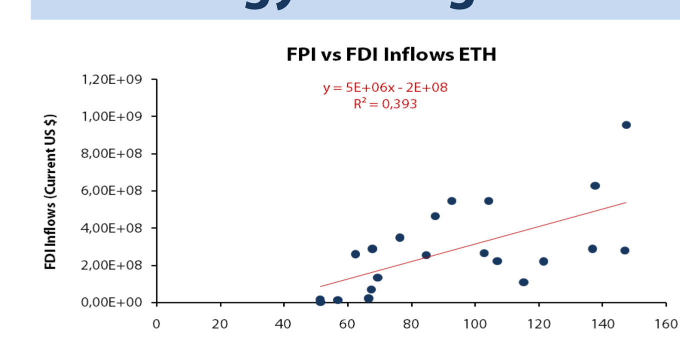
$$|\varepsilon_{BP}| = |\varepsilon_{BA} \cdot \varepsilon_{AP}|$$

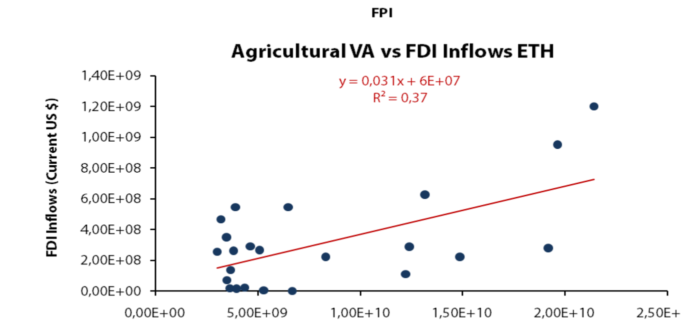
$$\left|\frac{(\Delta B/B)}{(\Delta P/P)}\right| = \left|\frac{(\Delta B/B)}{\Delta A/A} \cdot \frac{(\Delta A/A)}{(\Delta P/P)}\right|$$





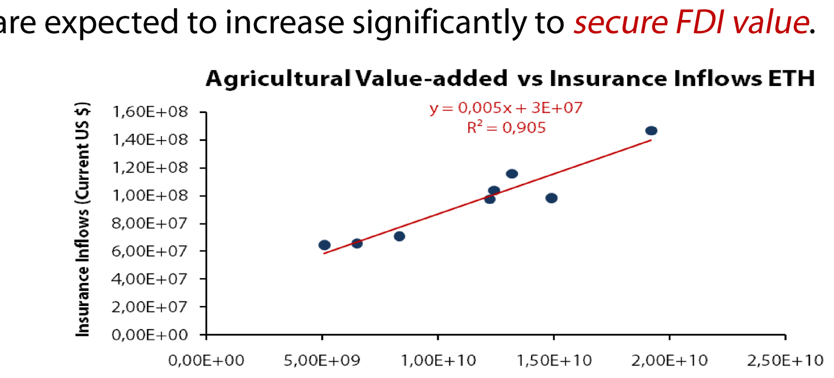
6. Energy and agrifinance trends in Ethiopia





The future of agrifinance in Ethiopia

Ethiopia experiences significant inflows of *Foreign Direct Investments* (*FDIs*); of which ~80% concern *arable land*. Ethiopia is differentiating rapidly its crop output but is still *vulnerable to hydroclimate extremes*. Thus, financial inflows of special instruments (i.e. weather derivatives) are expected to increase significantly to *secure FDI value*.



7. Conclusions

- ✓ The pattern of post-industrial global agriculture consists in its transformation from *net energy supplier* to a *net energy user*.
- ✓ The energetic transformation of global agriculture consists in: (a) *mechanization*, (b) extensive use of *fossil-fuel intensive fertilizers* and (c) *crop output differentiation*.
- ✓ Energy use increase per capita comprises an important factor not only for the growth of output, but also for *economic differentiation and complexity*.
- ✓ Ethiopia, as *Low Income Country* (LIC) follows the same path of agricultural transformation.
- ✓ With *human labor* and *energy* as major production factors –while lacking significant technological inputs- *crop output differentiation* is the optimal path of value maximization.
- ✓ The value of Ethiopia's agri-sector is still *heavily depended on hydroclimate conditions*, although with a decreasing trend as industry gains share in the GDP.
- ✓ Ethiopia's agri-sector attracts an *increasing value of FDIs*, concerning utilization of arable land.
- ✓ FDI inflows are expected to be accompanied by adequate *inflows of special financial instruments* in order to secure their future value against hydroclimate risks.

Sign Nomenclature

Progress Report

Conceptualization: Indicates a conceptual scheme or a theoretical visualization of an important energetic process

Complex System: Indicates the presence of a complex system across the performance of an energetic process

About the Author

Georgios Karakatsanis is an economist; graduate of ***Athens University of Economics and Business (AUEB)***, from which he received training in the field of *International Economics*. He continued his studies in ***National Technical University of Athens (NTUA)***, from which he gained a MSc. in the field of *Environment and Development*. Currently he is a joint PhD Candidate in ***NTUA*** and ***Technische Universität München (TUM)***. His core research interests are energy, water resources, economic development and growth, innovation finance, economic complexity, economic geography, econometrics and agriculture. His area of interest is Africa, with Ethiopia as his focus country, which experiences its first historical phase of development and industrialization via rapid increase of energy use.

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