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The Impact of Energy on Global Economy

Henri Safa[1,2]*

[1]I2EN, International Institute of Nuclear Energy, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France, [2]CEA, Scientific Direction, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France. *Email: henri.safa@cea.fr

ABSTRACT

The paper displays and explicit the interrelation that can be found between energy and economy. While energy is essential for human development, squandering should be prevented to avoid detrimental feedback from global warming. A better use of energy may enhance energy intensity but energy efficiency gains are hard to implement and slow. In order to evaluate the impact of energy on global economy, instead of using the usual statistical methods, we suggest an approach based on the production cost of products. Each activity sector is analyzed regarding its energy needs and related costs. The methodology has been applied to the case of France. It is found that energy affects over 60% of the global economy in France.

Keywords: Energy Impact, Gross Domestic Product, Economy, Energy Transition
JEL Classifications: Q4, Q43

1. INTRODUCTION

Mankind has always been relying on energy for development. In the 18th century, the industrial revolution has shifted production from human labour to machines driven by steam generated from burning coal. Following, new energy sources provided by natural resources were discovered like oil, gas and nuclear. Progressively, the energy used per capita worldwide has increased from 0.5 toe/capita, almost exclusively provided from biomass, to 2.0 toe/capita. In industrialized countries, the average is today twice that value, around 4 toe/capita. The drawback of this energy greed is the release of large quantities of carbon dioxide in the earth's atmosphere leading to a continuous global warming through the greenhouse effect. Consequently, many people around the world are advocating taking strong actions to force a reduction of the overall energy consumption through different instruments: Carbon tax, subsidies to renewable energies, energy price increase, environmental penalties on industries, etc. However, some environmental activists have sent mixed and sometimes misleading messages. The main objective for our planet is obviously to stop CO_2 emissions and not the reduction of energy consumption per se. As energy is required for human development, it would be unfair for undeveloped countries to refrain them from using more energy in a near future. Clearly, there is a strong interrelation between energy and economy. Of course, the energy sector drive many businesses by itself and is entirely part of the global economy. In some countries like oil Gulf States, it is even the major contributor. Nevertheless, in industrialized countries with no fossil fuel resources like France, all sectors of the economy are more or less dependent on energy. In this paper, we introduce a method for evaluating the weight of energy in every human activity, including non-profit organizations. For each activity, a number is calculated representing the impact of energy on this activity. A weighted average of the added value of the activity using the allocated number can then be computed for a given country. The resulting output may be considered as a figure of the impact of energy on the global economy.

2. ENERGY AND MACROECONOMY

2.1. Energy and Human Development

Numerous authors have pointed out the relationship between energy and human development (Ayres and Warr, 2009; Carbonnier and Grinevald, 2011; Cottrell, 1955). The industrial revolution starting in the late 18th century has been characterized by a transition from handmade production to manufacturing using mechanical work supplied by steam engines. The transition has been made possible thanks to the discovery of coal enabling a cheap production of steam power to drive the machineries. Coke has been also essential for iron fabrication and metallurgy. Coal required much less energy and labour to mine than cutting biomass from wood forests and embed 2-3 times more energy per unit mass than charcoal. The following human development in western countries has been since then relying on abundant and rather inexpensive energy available from fossil fuels.

It is very difficult to exactly quantify the level of human development in a given country going beyond the simple measure of the economic wealth. Nevertheless, following the work done by the United Nations, human development can be characterized by a single number, namely the Human Development Index[1] (HDI) as calculated by the United Nations Development Programme (HDI and UNDP).

Plotting the HDI as a function of energy consumption E (Figure 1) clearly exhibits two regions:

- All countries with low energy consumption E (<2 toe/capita) have also a low HDI. Clearly, a minimum of energy seems to be required for human development.
- There is no clear correlation above 4 toe/capita between HDI and energy consumption E. Above a given level, excess energy maybe considered as waste with a weak contribution, if any, to development.

This evidence gives the first piece of indication of the interrelation between energy and development. There is no human development without energy consumption. Therefore, the access to secure energy is mandatory for any kind of society no matter what.

2.2. Energy and Gross Domestic Product (GDP)

The GDP is a standard measure of the global economy of a country, quite similar to the economic indicator composing the HDI[2]. If one plots the time evolution of the GDP of a country as a function of the corresponding energy consumption per capita, a very clear correlation appears at low GDP (Figure 2). In every country, the first takeoff of its economy is bound to an increase in energy consumption up to a given level. At some point, in industrialized countries, the amount of energy consumption per capita will level off while GDP may continue to increase with time. In recent years, we do observe the premises of a slight decrease in energy consumption while GDP may still maintain its upward trend. One explanation for this apparent decorrelation of energy consumption from economic wealth could be the important recent investments in energy efficiency improvements. From the economical point of view, energy efficiency can be analyzed as a substitution of capital for energy. Furthermore, this substitution will ultimately show some limits as it will be disclosed in the next section.

Figure 1: Human development index versus energy consumption in selected countries

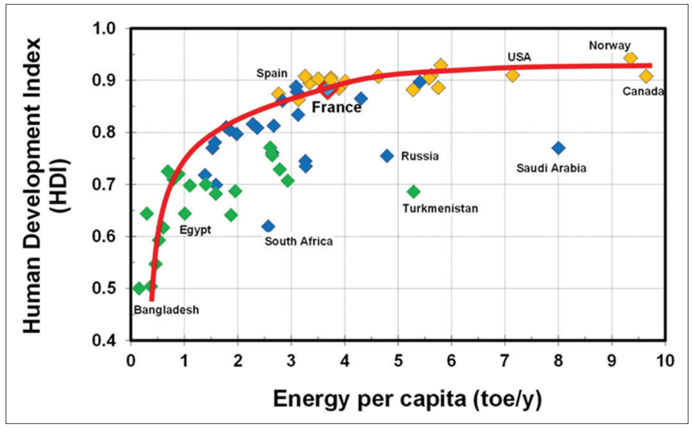
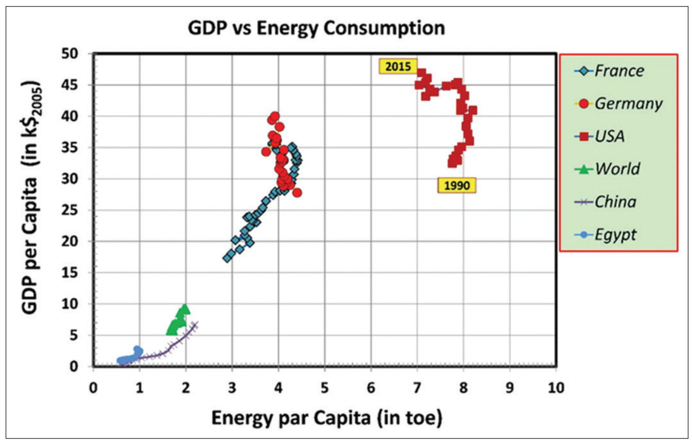


Figure 2: Evolution of the GDP and energy consumption for some countries (USA, China, Germany, France, Egypt) and worldwide as a function of time (1990-2015 for all countries except France 1970-2015)



Although the link between GDP and energy is quite clear and strong, there has been no direct theory providing an assessed figure for the impact of energy on GDP. Instead, a large range of economists use the econometrics techniques based on statistical correlations between GDP and energy consumption (Chontanawat et al., 2008; Kraft and Kraft, 1978; Soytas and Sari, 2003). These empirical approaches are usually based on regression models including Granger causality testing (Granger, 1969). The causality can be derived both ways, from energy to GDP and conversely from GDP to energy. We have decided to choose a completely different approach here. Instead of trying to find correlations from statistical a priori unknown variables (i.e. GDP and energy), we adopt a fully deterministic approach by evaluating the direct influence of energy on activities built up in the GDP. It is certainly a more tedious and long work than deriving best-fit values from a simple linear regression equation, but it is worth doing this task at least once because it also provides additional detailed information on the energy impact for every activity or sector.

1 Although perfectible, this index reflects the overall development of a country. It is mixture of 3 indicators lying between 0 and 1: The first on health, the life expectancy at birth, the second on education, the average and expected years of schooling and the third on economy, the gross national income (GNI). The HDI is calculated as the geometric mean of these 3 indicators.

2 The nominal GPD measures the market value of goods and services located in a country whereas the GNI measures the same values by citizenship owners. In summary, GNI = GDP - foreign residents in the country + national residents abroad. Therefore, the world GPD is identical to the world GNI.

2.3. Energy Intensity (EI)

By definition[3], the EI is the ratio between GPD and energy consumption E. The usual unit is $/toe.

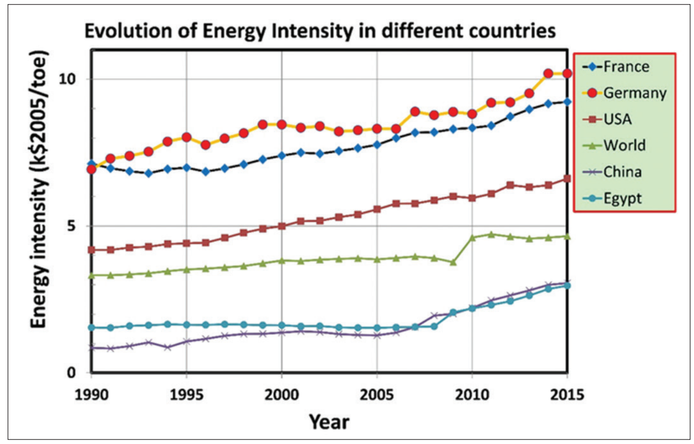
$$EI = \frac{GDP}{E}$$

EI has been steadily and continuously improving with time (Figure 3). On average, the world EI has more than doubled in a century, raising from 2100 $/toe in 1900 to 4650 $/toe nowadays. The rate of increase averaged over five decades is close to 1%/year. We may reasonably assume this trend will probably continue in the next decades.

One has to be very cautious when comparing the EI in between different economies as it may significantly differ with the structure of the economic agents. For example, labour-intensive countries may exhibit lower EI than countries having high-level services. However, for a given country, the EI is an indication of its energy efficiency over time. Historically, technological breakthroughs have tremendously improved the energy efficiency. The example of lighting whose efficiency has improved by a factor of 500 between 1820 and present time[4] is quite representative of how the trend is always pushing towards providing the same final use with lesser energy and at a lower cost (Fouquet, 2015). An adverse effect of this trend is the well-known rebound effect (Khazzoom, 1980) as people will naturally tend to be less concerned about energy savings when it becomes extremely cheap. This is for example the case of lighting today[5].

The improvement of energy efficiency is very slow in time and is bound to the progressive introduction of new technologies in all sectors of the economy. Public guidance, incentives and regulatory frameworks may enhance energy efficiency. However, there is a clear limitation to the amount that can be achieved from implementing these policies. A good example is the energy savings in the construction sector and buildings. Acting on the building envelope to reduce heating or cooling losses will result in energy savings in the long run at the expense of an added investment cost during construction or renovation. It is obvious that this will result in a trade-off between the actual cost increase and the sum of all future savings resulting from energy gains. The optimum value will certainly not end up being a full and tight insulation of the building walls and roofs to achieve zero losses. Aiming at zero energy buildings would lower the energy consumption of the residential and commercial sectors but would also be economically counter-productive, leading to higher costs for housing and a lower well-being for the people willing to access to home ownership. Actually, one might reconsider the energy efficiency policies towards refocusing on increasing energy productivity instead, which means increasing the economic value of each unit of energy consumed rather than increasing the EI.

Figure 3: Energy intensity is improving over time worldwide



Nevertheless, as soon as a new technology is introduced then deployed in an industry or within an economic sector, the trend will always be towards trying to enhance the energy efficiency of this technology with time at an affordable cost. The historical observation lead to an average increase rate of the global EI that has been oscillating between +0.7%/year and +1.0%/year over the last 50 years. And unless some revolutionary technology is going to be introduced in the energy landscape, the situation will continue to evolve at the same pace. Only disruptive technologies can readily and abruptly alter the established trend. Some examples of these so-called "energy game changers" shall be highlighted and described later on.

2.4. The KLEM Approach

Traditionally, economic theories use the Capital-Labour (KL) input variables for productivity (Courbis and Templé, 1975; Davis, 1955). The value-added (VA) is deduced as a function of these two parameters VA = f (K,L). Productivity is improved by i) a more effective output from human workers and ii) by the introduction of machines and computers. However, new approaches suggest including explicitly two other inputs: Energy (E) and materials (M). These theories, known as the KLEM approach (Saari, 2006), recognize the importance of energy and materials required for any production. Previously, Energy and Materials were implicitly embedded in the capital assets and were merely considered as supplies at a given price. Modern theories acknowledge the fact that these inputs are unavoidable in a first place and in finite quantities on earth. Resources availability are key to sustainability, ensuring today's needs without compromising the ability of future generations to meet theirs. Consequently, even though their capital share is not predominant, their impact might turn out to be of prime importance in numerous business activities. In this paper, we shall only focus on the impact of energy (E) on the production cost (CP) excluding labour (L), as a function of the 3 inputs:

CP = f (K,E,M)

3 Energy Intensity is sometimes defined as the inverse ratio (Energy/GDP). Our selected definition is more appropriate as a better efficiency refers to an increase - and not a decrease - in energy intensity.

4 Fouquet (IEA Report, 2016) compares a modern LED light with an intensity of 66000 lumen per kWh to an old gas lamp used in 1820 to generate 130 lumen/kWh. He calculated the equivalent cost of lighting to be 2700 more expensive in 1820 than today.

5 In 2015, lighting represented <7% of the global electricity consumption in the residential sector and 2% of the total electricity consumption in France. Moreover, this contribution is expected to further decrease in the coming years with the introduction of more efficient lamps like LED in the market.

The derivative regarding the energy variable is (equation 1):

$$\left(\frac{df}{dE}\right)=\left(\frac{\partial f}{\partial K}\right)\left(\frac{dK}{dE}\right)+\left(\frac{\partial f}{\partial E}\right)+\left(\frac{\partial f}{\partial M}\right)\left(\frac{dM}{dE}\right) \quad (1)$$

The global impact of energy E on the production cost CP shall be derived as a non-dimensional number

$$\xi=\frac{dLogf}{dLogE}$$

ξ is a number between 0 and 1 and represents the percentage of production cost change upon a change in energy prices. In particular, if the energy price is for example doubled, the production cost will increase by a factor of $(1+\xi)$. $\xi = 0$ means no impact of energy on production cost. $\xi = 1$ means full impact of energy on production cost. Of course, each activity A_i will exhibit a different impact value ξ_i.

2.5. Methodology

In order to estimate the global impact of energy on economy, we will divide the economy for a given country in sectors gathering similar type of activities. In France, following the INSEE splitting of the 732 sub-class activities, we will sort out the impact values ξ_i for each of the 38 branches and/or the 88 divisions of the national economy. The nomenclature list has been redefined in 2008 to be consistent within all European Union countries and can be found in reference (INSEE, 2008). Each year, the statistical agency will provide a table giving the intermediate inputs in terms of economic cross-relation between each branch. We shall use this table as a matrix $A = (A_{ij})$ in which each activity A_i is buying goods and services from all other activities A_j in order to conduct its own business.

If (ξ_i) is the energy impact on each branch or sector, then, we must find that

$$\xi_i=\frac{\sum_j\left(A_{ji}.\xi_j\right)}{\sum_j\left(A_{ij}\right)}$$

Of course, by definition, if the activity considered is embedded in the energy sector, $\xi_i = 1$.

The self-consistency of all values (ξ_i) will fully determine those numbers given the matrices identity (equation 2):

$$(\xi) = (X)\,(\xi) \quad (2)$$

In which $x_{ij}=\frac{A_{ij}}{\sum_j\left(A_{ij}\right)}$

Because $\sum_j (x_{ij}) = 1$ for all values of the index i, the square matrix (X) is degenerate. Setting $\xi_E = 1$ allows removing the degeneration and consequently solve the equation and fix all the values (ξ_i).

Following, the energy impact on each activity A_i can be calculated using equation 1:

$$\xi_i=\xi_{Ki}\left(\frac{\partial Logf}{\partial LogK}\right)_i+\xi_{Ei}\left(\frac{\partial Logf}{\partial LogE}\right)_i+\xi_{Mi}\left(\frac{\partial Logf}{\partial LogM}\right)_i$$

$$\xi_i = \xi_{Ki}.g_{Ki}+\xi_{Ei}.g_{Ei}+\xi_{Mi}.g_{Mi}$$

Where, $g_{Ki}=\left(\frac{\partial Logf}{\partial LogK}\right)$, $g_{Ei}=\left(\frac{\partial Logf}{\partial LogE}\right)$ and $g_{Mi}=\left(\frac{\partial Logf}{\partial LogM}\right)$ are the 3 derivative components of the production cost CP of activity A_i regarding respectively capital (K), energy (E) and materials (M). Again, all g values are between 0 and 1 and the sum $(g_K+g_E+g_M)$ is exactly equal to unity. Of course, one always have $\xi_{Ei} = 1$.

In a similar manner, the importance of energy on the global economy is calculated as

$$\xi = \xi_K.g_K+\xi_E.g_E+\xi_M.g_M$$

3. APPLICATION TO THE CASE OF FRANCE

3.1. National GDP in France

The GDP is the sum of gross added values of all activities plus taxes minus subsidies. The GDP for France was around 2000 G€ in 2014[6]. All activities require more or less energy for production, would it be for manufacturing, heating, lighting or simply working on computers. The total sum of added values of activities amounts to 1918 G€ (Table 1) and constitutes the main bulk (90%) of GDP. The added value of the energy sector is <2% of GDP. The total energy supply for France was 254 Mtoe, about half of it used for electricity generation mainly through domestic nuclear and hydraulic power plants. The other half are predominantly imported fossil fuels, like oil for transportation and gas for heating. Therefore, at a first sight, it looks like the energy production cost impact on the global economy should be very small if not negligible. Actually, this first impression is quite misleading, as it will be demonstrated hereafter.

4. RESULTS

The above methodology described in § 2.5 has been applied using the intermediate table of inputs (Matrix A) given by the statistics for year 2014 (INSEE, 2014). The energy production activity (labeled A38.DZ) includes the production of all types of energetic utilities (electricity, gas, steam) that are supplied to all other sectors. The vector (ξ) has been calculated by solving the self-consistent equation 2 and the results are summarized in the following table. The calculated value for the overall impact of energy ξ on the production of goods and services is 61%.

4.1. Validation of Results

We shall take two examples to illustrate the results obtained, one in the manufacturing industry and the other in the service sector. The first is car manufacturing, an important subsection of A38. CL (Manufacturing of transport equipment). All materials entering

6 More precisely 2140 G€ in 2014 current currency or 2056 G€2010 in Euros of 2010.

Table 1: Results for all activities in France grouped in 38 main domains

Nomenclature	Activity	VA (G€)	L (G€)	K (G€)	E (G€)	M (G€)	CP (G€)	g_K (%)	g_E (%)	g_M (%)	ξ_K (%)	ξ_E (%)	ξ_M (%)	ξ (%)
A38.AZ	Agriculture, forestry and fishing	33.2	9.8	19.5	5.1	29.8	54.4	36	9	55	62	100	63	66
A38.BZ	Mining and quarrying	2.2	1.0	2.1	0.3	0.9	3.3	63	10	27	57	100	63	63
A38.CA	Manufacture of food products, beverages and Tobacco	44.5	22.8	27.3	3.7	83.4	114.4	24	3	73	57	100	63	63
A38.CB	Manufacture of textile, wearing apparel, leather and related products	4.9	3.3	3.4	0.3	7.5	11.2	30	3	67	60	100	60	61
A38.CC	Manufacture of wood, paper and printing	10.9	8.2	9.4	1.8	13.7	24.8	38	7	55	59	100	62	64
A38.CD	Manufacture of coke and refined petroleum products	2.2	0.8	8.8	4.8	32.8	46.5	19	10	71	59	100	63	66
A38.CE	Manufacture of chemicals and chemical products	17.5	8.9	27.2	11.1	10.6	48.9	56	23	22	65	100	62	72
A38.CF	Manufacture of pharmaceutical products	11.5	4.2	10.7	0.3	2.1	13.2	81	3%	16	60	100	62	62
A38.CG	Manufacture of rubber and plastic products	17.9	12.4	19.6	2.1	11.9	33.7	58	6	35%	63	100	63	65
A38.CH	Manufacture of basic metals and metal products	25.2	18.7	18.5	3.4	33.6	55.5	33	6	60	58	100	61	62
A38.CI	Manufacture of computer, electronic and optical products	10.1	6.4	8.2	0.3	3.3	11.8	69	2	28	57	100	62	59
A38.CJ	Manufacture of electrical equipment	6.3	4.8	8.2	0.3	5.4	13.8	59	2	39	58	100	62	60
A38.CK	Manufacture of machinery and equipment N.E.C.	12.6	8.3	15.4	0.5	9.2	25.1	61	2	37	57	100	61	60
A38.CL	Manufacture of transport equipment	20.1	13.8	71.8	1.1	18.2	91.1	79	1	20	57	100	62	58
A38.CM	Other manufacturing and repair and installation of machinery and equipment	29.9	21.6	24.5	0.5	12.4	37.4	65	1%	33	58	100	62	59
A38.DZ	Electricity, gas, steam and air conditioning supply	34.7	11.9	13.4	41.9	14.0	69.3	19	60	20	60	100	62	100
A38.EZ	Water supply; sewerage, waste management and remediation activities	13.6	7.3	9.8	1.1	11.5	22.4	44	5	51	56	100	60	60
A38.FZ	Construction	111.1	69.1	105.7	3.6	54.9	164.2	64	2	33	57	100	62	60
A38.GZ	Wholesale and retail trade; repair of motor vehicles and motorcycles	194.8	131.1	170.2	9.8	16.6	196.7	87	5	8	57	100	62	60
A38.HZ	Transportation and storage	87.6	60.1	77.3	18.8	3.6	99.8	77	19	4	60	100	62	68
A38.IZ	Accommodation and food service activities	53.5	32.1	14.3	1.3	30.2	45.7	31	3	66	56	100	61	60
A38.JA	Information and communication: publishing, broadcasting and audiovisual	23.9	14.1	17.4	2.0	8.5	27.9	62	7	30	58	100	62	62

(Contd...)

Table 1: ***(Continued)***

Nomenclature	Activity	VA (G€)	L (G€)	K (G€)	E (G€)	M (G€)	CP (G€)	g_K (%)	g_E (%)	g_M (%)	ξ_K (%)	ξ_E (%)	ξ_M (%)	ξ (%)
A38.JB	Telecommunications	23.3	9.0	27.8	1.5	2.5	31.7	87	5	8	56	100	62	59
A38.JC	Computer and information service activities	45.8	32.9	25.8	0.6	1.2	27.6	93	2	4	56	100	61	57
A38.KZ	Financial and insurance activities	87.6	49.4	123.9	1.0	2.4	127.3	97	1	2	54	100	62	54
A38.LZ	Real estate activities	246.3	15.2	51.9	0.6	2.4	54.9	95	1	4	54	100	61	55
A38.MA	Legal and accounting, management, consultancy, architectural, engineering and technical & testing activities	94.1	73.0	113.4	2.3	6.3	122.1	93	2	5	55	100	62	56
A38.MB	Scientific research and development	33.4	19.2	24.4	0.6	2.7	27.6	88	2	10%	56	100	61	57
A38.MC	Other professional, scientific and technical activities	14.9	9.9	13.4	0.7	1.6	15.7	85	4	10	56	100	61	59
A38.NZ	Administrative and support service activities	102.6	67.4	64.9	2.0	7.2	74.1	88	3	10	56	100	61	57
A38.OZ	Public administration and defence; compulsory social security	158.1	116.1	45.2	3.3	7.9	56.4	80	6	14	57	100	60	60
A38.PZ	Education	104.9	91.1	16.1	1.6	6.0	23.7	68	7	25	57	100	61	61
A38.QA	Human health activities	115.1	65.3	32.3	1.1	6.1	39.6	82	3	15	57	100	61	59
A38.QB	Residential care and social work activities	65.3	59.4	11.3	0.7	1.9	13.9	81	5	13	56	100	61	59
A38.RZ	Arts, entertainment and recreation	25.9	19.5	17.0	1.8	3.9	22.7	75	8	17	57	100	61	61
A38.SZ	Other service activities	28.6	19.3	12.9	0.6	1.8	15.3	84	4	12	56	100	62	59
A38.TZ	Activities of households as employers; undifferentiated goods and services producing activities of households for own use	3.6	4.9	0.0	0.0	0.0	0.0	100	0	0	50	100	50	50
	Sum	1.918	1.122	1.263	133	468	1.864	68	7	25	57	100	62	61

VA: Added value, L: Labour, K: Capital, E: Energy, M: Materials, CP: Production cost w/o labour, g_K: Capital share, g_E: Energy share, g_M: Materials share, ξ: Impact of energy in the fabrication of a light-duty vehicle (Keoleian and Sullivan, 2012) can be detailed in Table 2 and each weighted with its energy impact on parts and components.

While the direct energy consumption of a car manufacturer is $< g_E = 2\%$ of total production costs, the embedded energy cost in materials purchased amount to 19% of the production cost of a vehicle excluding labour, with an energy impact on materials of $\xi_M = 62\%$ (Table 2). If we also take into account the energy impact on the capital needed for fabrication including machineries, tools and buildings, the overall energy impact on manufacturing costs is $\xi = 55\%$.

The second example is a hotel business, a subsection of A38.IZ (Accommodation and Food Service Activities). We evaluate the different costs per room using the data statistics given in reference (KPMG Report, 2013) for different hotel classifications and averaged them over the total number of available rooms in France. Here again, the deduced energy impact ξ precisely matches the calculated one in the relevant domain (Table 3).

4.2. The Importance of Energy in the Global Economy

In all type of activities, even if the corresponding domain requires very little energy like for example the real estate branch, the corresponding energy impact value ξ is above 50%. The reason is that capital K as well as materials M are both requiring energy to be delivered and their corresponding factor ξ_K and ξ_M turn out to be for both of them above 50%. Overall, the impact of energy on the global economy of France is calculated to be $\xi = 61\%$. This translates to a general impact of energy on GDP in the order of 40%. Although energy is only contributing on average to about 7% of the production cost of all products, its indirect impact is much higher and is ultimately significantly influencing the total production cost. This result establishes a clear and direct relation between energy, production cost and GDP. In any case, in-house cheap energy production will be favored to yield benefits and higher growth. At the opposite, imported expensive energy will induce a poorer competitiveness in all activities and lead to economic recession.

Table 2: Materials entering in the composition of an average light-duty vehicle and share of energy impact ξ_M for each material

Material	Mass share	Mass per vehicle (kg)	ξ_M (%)
Steel	54.3	679	69
Plastics	9.8	123	52
Aluminium	8.3	104	83
Iron	5.2	66	46
Rubber	5.4	68	33
Glass	2.4	30	42
Others	14.5	182	58
Total	100	1250	62

Table 3: Expenses splitting for an average accommodation room in hotels in France. Materials include food, beverages and O and M expenses

Service costs	Average costs per room (€)	Share (%)	ξ (%)
L	34.2		
Total with labour	75.7		
E	3.5	8	100
M	20.3	49	66
K	17.8	43	45
Total without labour	41.5	100	60

L: Labour, K: Capital, E: Energy, M: Materials

At this point, we have not taken into consideration changes that may arise concerning the imports of goods and services. In fact, we have implicitly assumed that the energy cost is changing at a world scale affecting in a same manner production costs for energy, material and capital in all countries. This assumption is certainly valid at the first order as energy price modifications, like for example oil imports, are almost identical worldwide. However, changes might occur in domestic energy production costs from one country to another, affecting the energy contents of imported goods and services. Therefore, in order to be rigorous, the above figures derived from our methodology ought to be corrected accordingly and are only valid whenever a product uses a significant part of its energy and materials from national businesses. In the case of France, the imports weigh around 13% of the sum of all products value. Consequently, one might consider that the correction brought by imports will be probably limited and that our initial assumption is valid to the first order of magnitude.

5. ENERGY AND CLIMATE CHANGE

5.1. Greenhouse Gas Emissions

Burning fossil fuels (coal, oil and natural gas) releases carbon dioxide in the earth's atmosphere. This energy-induced pollution is the main contributor to greenhouse gases (GHG) that are slowly but steadily affecting our climate. Greenhouse effect will induce a global warming of the atmosphere that could potentially lead to catastrophic uncontrollable events on our planet within a century. We must definitely alleviate this threat by a strong and deliberate reduction of our GHG emissions. To do so, a number of economists are advocating a simple and effective universal carbon tax on GHG emissions above 100 \$/ton of CO_2. Today, the world energy consumption amounts to 14 Gtoe. At an average price of 230 \$/toe, this energy production is costing 3200 G\$ per year representing 4% of the total world GDP. At the same time 34 Gt of CO_2 equivalent GHG are released every year. If a blunt carbon tax of 100 \$/t is uniformly applied, this means energy costs will be roughly doubled. Considering the level of the energy impact on economy described in this paper, this might not be affordable, especially in many developing countries. A catastrophic global economic depression may result. The remedy might turn out to be worse than the disease.

5.2. The Energy Transition

A very smooth energy transition is required. A decisive and strong reduction in GHG emissions within a few decades will only happen if a voluntary shift is performed from today's energy mix relying on fossil fuels (oil, coal and gas) towards clean energies like hydro, nuclear and renewables. Because many countries will need more and more energy to develop, the goal is not a reduction in the total energy consumption but rather a strong incentive to promote carbon-free energies. In particular, two energy game changers may pave the way for a genuine energy transition: The switch to electric vehicles for road transportation and the recovery of waste heat from electric power plants (Safa, 2012) for housing, business centers and industry processes. We shall here give some insights on these two major disruptive technologies.

6. ENERGY GAME CHANGERS

6.1. Cogeneration of Electric Power Plants

Since the first turbines installed at Niagara Falls in 1882, immediately followed 1 year later by the first hydroelectric production in France[7], electric power has been continuously spreading all over the world. Electricity is a very practical energy vector, flexible, handy, reliable, avoiding the risks of chemical fuels like explosions or poisoning. This is why many applications progressively switch to using electricity instead of standard fuels. While energy consumption has been increasing at a rate of 1.7%/year since two centuries, electricity is increasing even faster at an average rate of 3%/year, giving evidence of the substitution. In 1965, 20% of the world energy resources were supplying electric power plants. Today, electricity accounts for 38% of primary energy in the world and have exceeded 50% in some industrialized countries like France. However, power plants are today primarily dedicated to produce only electricity. Yet, the efficiency of the conversion process from heat to electric power is quite low, ranging from 35% for nuclear power plants to 40% for coal and gas-fired, up to a maximum of 60% for advanced combined cycle gas plants. Therefore, roughly half of the generated heat from burnt fuels is simply wasted in the environment through the cooling systems, be it cooling towers, rivers or seawater cooling. There is a tremendous amount of waste heat at electric power plants. In 2014, out of the 5.14 Gtoe of input energy fueling the total electric plants in the world, 2.77 Gtoe were wasted. Most of this heat can be recovered to feed the needs of the residential dwellings, the commercial businesses as well as serving a significant part of heat energy required by some industrial processes. The recovery is technically achievable and can be performed by modifying any electric power plant to run in a cogeneration mode, providing at the same time electricity as well as heat. There are many benefits from operating an electric power plant in a cogeneration mode. The first is evidently the energy efficiency that may exceed 80% in case of a full recovery of wasted heat. At the same time, the energy produced is properly used in the right final form and at the right temperature avoiding unwanted transformations that are sources of losses. The second benefit is economical because waste heat can be recovered at a very low cost when compared to any other fossil fuel burning plant. Even though initial investment is required for heat transport and heat distribution, the final cost of the delivered heat will offer cheaper energy to the consumer. In any case, after amortization, waste heat is the cheapest of all no matter what. Another economical benefit is the corresponding reduction of burnt oil, gas and coal fuel quantities, which in countries like France are expensive imported goods. Cogeneration will relieve the country balance of trade and thus improve the security of its energy supply. Moreover, the expected foreseen rarefaction of fossil fuels reserves will tend to make this issue even more critical in the future. Finally, the third and most important benefit is environmental. Burning natural gas to produce heat results in GHG emissions of approximately 200 g/kWh. Consequently, recovering the waste heat of a 1 GW power plant will reduce the CO_2 emissions by as much as 1.7 million tons/year. Considering that the total installed power in the world is approaching 7000 GW, this indicates that the amount of GHG abatement by implementing this technology is worth more than 10 billion tons of CO_2. This alone points out the scale of the important environmental advantage that can be derived from implementing cogeneration in electric plants. In summary, cogeneration induces savings in energy, in costs and helps reducing the GHG emissions of the power sector.

7 In 1883, 3 turbines were installed on the Valserine River to produce electric power for public lighting in the city of Bellegarde, France.

6.2. Electric Transportation

Today, transport is highly dependent on oil resources as 92.3% of world energy for transportation is using oil products. The reason is the very high energy density of liquid fuels (11600 Wh/kg), almost two orders of magnitude higher than electrochemical batteries (100-300 Wh/kg). However, electric motors have a much better efficiency than conventional combustion engines fed with gasoline fuels. Two important barriers are refraining the commercial expansion of electrical vehicles: High battery costs and low mileage autonomy. This year, the market share for electric cars is expected to be lower than 1% of the global vehicle market in many countries (IEA Report, 2016). National incentives and policy support are necessary to achieve widespread deployment of electric cars, to provide easy access to recharging infrastructures and promote awareness and confidence in the technology. Price drop will occur with mass production and with technology improvements of the battery cells. Mileage range will increase with a higher energy density of cells, still far today from their intrinsic physical limit. Nevertheless, a 400 km mileage range is enough for the vast majority of consumers. Because road transport is responsible for an annual emission of 5.3 billion tons of CO_2, a complete switch from internal combustion engines cars to electric vehicles can save an additional 15% of the global energy-related GHG emissions provided electricity is produced from carbon-free sources, which brings us back to the previous discussion on power plants.

7. CONCLUSION

Although energy is only weighing between 2% and 7% of GDP in western developed countries, its importance is crucial in all activities of our modern economies. In this paper, we provide a methodology to quantify as precisely as possible the economic impact of energy in all sectors for a given country. The result is that energy affects over 60% of the global production costs in France. Consequently, if the energy transition requires an increase in energy costs through either carbon taxes or other national incentives, people should be aware about carefully evaluating the counteracting slowdown this might induce on the global economy. Technology breakthroughs are essential to ease the energy transition from fossil fuels to carbon-free sources while generating economic benefits. In particular, two energy game changers if combined are likely to answer the issue brought up by climate change. The first is the cogeneration of electric power plants and the second the electrification of transport through the deployment of electric vehicles.

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