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Article

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Reference: Lianos, Theodōros P./Pseiridis, Anastasia N. et. al. (2020). On the relationship between gross domestic product and energy : a critical comment. In: International Journal of Energy Economics and Policy 10 (2), S. 458 - 463.
https://www.econjournals.com/index.php/ijeep/article/download/8418/4919.
doi:10.32479/ijeep.8418.

IJEEP
INTERNATIONAL JOURNAL OF ENERGY ECONOMICS AND POLICY
EJ EconJournals ISSN: 2146-4553

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2020, 10(2), 458-463.

EJ EconJournals

On the Relationship between Gross Domestic Product and Energy: A Critical Comment

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Received: 17 July 2019 **Accepted:** 20 December 2019 **DOI:** https://doi.org/10.32479/ijeep.8418

ABSTRACT

Since 1978, an important literature has been developed on the relationship between gross national product and energy. The obvious interest in this relationship is a result of the global interest in reducing the use of energy without impairment of economic growth. Most studies do not have an economic model underlying the statistical models. In the absence of an economic model supporting the estimable equations, the statistical results can be interpreted arbitrarily or they may not have an interpretation that can be theoretically supported. In this paper we attempt to do four things. First, we briefly present the four hypotheses that have been formulated to express the energy-gross domestic product (GDP) relationship. Second, we argue that the relationship between GDP and energy, as is formulated in two of the hypotheses (the growth hypothesis and the feedback hypothesis), and as is examined in part of this literature, suffers from misspecification, because a decisive factor for the energy market is missing. Third, we use basic economic theory to show how GDP and energy are related on the basis of production theory and derived demand for factors of production, and, fourth, we conclude by suggesting which of the four hypotheses can serve as a meaningful approximation of the relationship.

Keywords: Gross Domestic Product-energy Nexus, Conservation Hypothesis, Growth Hypothesis, Feedback Hypothesis, Neutrality Hypothesis
JEL Classifications: Q41, Q43

1. INTRODUCTION

Since 1978, when Kraft and Kraft (1978) published their seminal three-page paper on the relationship between gross national product and energy, an important literature has been developed on this issue. The obvious interest of researchers in this relationship is a result of the global interest in reducing the use of energy so that economic growth will not be impaired. There are already at least six reviews (Kalimeris et al., 2014; Menegaki et al., 2017; Ozturk, 2010; Menegaki, 2014; Hajko, 2017 and Beaudreau, 2010), two of which (Menegaki et al., 2017; Hajko (2017) are very recent. The conclusion regarding the results of this line of research is rather disappointing. In the words of Kalimeris et al. (2014), their attempt "to examine the concreteness and consistency of the debate's result by means of meta-analysis failed to define a robust macro causality direction and, moreover, failed to identify general factors and causal relationships determining the directionality" (p9). This failure is attributed to the fact that the examined studies differ in the time period covered, in the characteristics of the economies, in the different climatic conditions, in the sources of data, and also in the econometric methods used.

The energy-gross domestic product (GDP) nexus is an economic relationship. Energy is used systematically only for the production of goods and services and GDP cannot be produced without energy. It is an if and only if relationship[1]. However, the reader of this

1 There are, of course, goods and services that are not included in the measurement of GDP as for example those produced within the household. However, the energy used in the production of these commodities is usually measured and therefore the estimated energy-GDP relationship is only an approximation of the real one.

literature cannot but observe that most studies of the energy-GDP relationship are not based on an explicit economic model underlying the statistical models. In the absence of an economic model supporting the estimable equations the statistical results can be interpreted arbitrarily or they may not have an interpretation that can be theoretically supported.

In this paper we attempt to do four things. First, we present very briefly the four hypotheses that have been formulated to express the energy-GDP relationship. Second, we argue that the relationship between GDP and energy as is formulated in two of the hypotheses, the growth hypothesis and the feedback hypothesis, and as is examined in part of this literature suffers from misspecification, in the sense that a decisive factor for the energy market is missing. Third, we use basic economic theory in order to show how GDP and energy are related on the basis of production theory and derived demand for factors of production, and fourth, we conclude by suggesting which of the four hypotheses can be a meaningful approximation of the relationship.

As the title of this paper suggests, it is critical comment and therefore we do not attempt a detailed review of the many studies on this subject. Our aim is to concentrate on the substance of the relationship and not on the results of the various studies. The papers we have already cited are sufficient for our purposes.

2. THE GDP-ENERGY NEXUS

Generally speaking, there are four possible relationships between GDP and energy consumption regarding the existence and the direction of causality, and four hypotheses have been formulated in the literature. Briefly, these hypotheses go as follows:

I. Conservation hypothesis. According to this hypothesis GDP and energy consumption are causally related with causality running from GDP to energy. Thus, real GDP growth increases energy consumption. From this relationship, the implication is that any conservation policies concerning energy consumption will have no effect on GDP growth
II. Growth hypothesis. According to this hypothesis GDP and energy consumption are causally related with causality running from energy to GDP. It implies that energy consumption causes GDP growth. It is claimed that, if this relationship actually exists, the availability of energy will cause GDP growth and that conservation policies would have negative effects on economic growth
III. Feedback hypothesis. According to this hypothesis GDP and energy consumption are causally related with causality running both ways from GDP to energy and from energy to GDP
IV. Neutrality hypothesis. According to this hypothesis GDP and energy consumption are not causally related and therefore their changes are independent of each other. The implication is that GDP growth does not affect energy consumption and at the same time the availability of energy does not affect GDP growth.

The rather surprising result of the statistical tests that have been performed is that all these hypotheses have been given support by various studies. Before we discuss the theoretical foundation of these hypotheses or the lack of it, it is necessary to remind the reader that causality in the real sense cannot be proven by the Granger causality tests or other statistical techniques. Predictive power does not mean causality in an economic sense. If we see people getting out of their homes holding an umbrella we may predict that it will probably rain but we cannot claim that carrying umbrellas causes rain. The old *post hoc ergo propter hoc* fallacy should be kept in mind. According to David Hume, causality cannot be observed. Coincidence in time and in space does not prove causality. Causal connection requires necessary connections. The closest we can get to necessary connection in economics is by means of structural models.

Let us now examine the four hypotheses stated above under the light of basic economic theory and comment on their validity. According to the theory of production, the conservation hypothesis is valid. The production of goods and services requires inputs, energy being one of them. If production increases (decreases) more (less) energy will be needed and therefore changes in production necessitate changes in energy in the same direction. This is so for all products and services included in the GDP and therefore it is correct to say that GDP and energy consumption are causally related, with causality running from GDP to energy. However, the implication derived from it, namely that energy conservation policies will have no effect on GDP growth, involves a misunderstanding of the relationship. If energy is an input in the production of GDP, the lack of energy will put a restriction on the growth of output or it will have to be substituted by other inputs and/or other technological methods of production should be used. In other words, if the conservation hypothesis is valid, the opposite from the usual implication should be derived: restrictions on the use of energy will, ceteris paribus, mean, sooner or later, restrictions on production. Therefore conservation policies should be studied very carefully and in relation to possibilities of substitution of other inputs for energy.

The growth hypothesis suggests that the direction of causality between GDP and energy use is from energy use to GDP. This is implausible unless it can be argued that increasing use of energy will increase effective demand and thus increase GDP. But if the price of energy is above zero it is difficult to think of using energy for any other reason except for the production of goods and services. The line of reasoning of the growth hypothesis cannot be supported. The growth hypothesis would be meaningful if it is stated in terms of energy availability instead of energy use, but the connection between energy and GDP will be indirect. Increasing availability of energy will reduce its price, reduce the cost of production, raise the profitability of firms, increase investment and finally lead to GDP growth. But this is an indirect effect and far from certain. As a direct effect, this is impossible. This is the same as saying that if labor is available it will necessarily be employed and give rise to GDP, something we know is not true. The availability of energy can have an effect on GDP growth but this can happen only through the mediation of the market for energy and, in this case, the relationship between the two variables is derived from the market mechanism and does not have the nature of a hypothesis of the same status as the conservation hypothesis. In fact, it is not certain that increasing availability of energy will increase production, since this depends on a number of other factors such as business expectations, the state of the trade cycle, and the reaction of businesses to lower energy prices.

The feedback hypothesis contains the conservation and the growth hypotheses, but it is not clear how they operate. Do they operate independently and, if so, do they operate at the same time or each causality direction is at work at different times and under different circumstances? Or does one causality direction set in motion the opposite? The feedback hypothesis suffers from the same misunderstanding as the growth hypothesis since the latter is part of the former. In fact, it is in essence self-contradictory. According to the conservation hypothesis, if GDP grows then the use of energy will increase, demand for energy will increase, and, ceteris paribus, its price will also increase leading to a new equilibrium position. No feedback should be expected.

The neutrality hypothesis states that energy use and GDP are not causally related. Therefore, their motion is determined by different independent factors. This hypothesis implies that the production of GDP does not require energy as an input and at the same time that energy is used for purposes other than the production of goods and services, e.g., for fun, where fun is not defined as a service that produces utility. If such is the case, GDP and energy use could move independently. However, this case cannot be defended. It is difficult to think of circumstances where energy would be systematically demanded and used other than the production of commodities and where commodities are produced without the use of energy.

It is, therefore, fair to say that the conservation hypothesis is valid; the growth and the feedback hypotheses are based on a misunderstanding of the relation between the production function and the derived demand for inputs; and the neutrality hypothesis is unfounded and implausible.

3. THE GDP-ENERGY NEXUS IN ECONOMIC THEORY

In this section we use the theory of production (e.g., Henderson and Quandt, Ch. 3, 1971) to examine how GDP and energy use are connected and how the nexus between the two can be estimated. According to economic theory, there is a strong causal relationship between GDP and energy with causality running from GDP to energy. This is clearly shown in the production function.[2] Assume for simplicity a production function of the Cobb-Douglas type

$$Q = A_0 K^{a1} L^{a2} E^{a3} \quad (1)$$

Because of lack of data on global capital (K) and labor (L), for our purposes, this production function can be rewritten as

2 Ghali and El-Sakka (2004) base their analysis on the production function but in their econometrics they use product and inputs as if they perform the same function. Also, Stern (2000) and Apergis and Payne (2009) use capital and labor as well as energy as inputs in creating a multivariate framework where product and inputs are assumed to function in the same way.

$$Q = Aa(t)\, E^{a3} \; 0 < a_3 < 1 \quad (2)$$

where the factor $a(t)$ assumes energy augmenting technological progress. Technological progress can take two forms, namely $a(t) = ae^{\lambda t}$ which implies a constant rate of technological change $\left(\frac{\dot{a}}{a} = \lambda\right)$ or $a(t) = \alpha^{\lambda t}$ which implies a declining rate of technological change over time $\left(\frac{\dot{a}}{a} = \frac{\lambda}{t}\right)$.

If we assume that $a(t) = \alpha e^{\lambda t}$, production function (2) can be estimated in logarithms as

$$lnQ = lnA + ln\alpha + \lambda t + \alpha_3 lnE \qquad \text{or}$$

$$lnQ = (lnA + ln\alpha) + \lambda t + \alpha_3 lnE \quad (3)$$

Since the parameter α is unobserved practically the same estimable equation is obtained if $a(t) = \alpha^{\lambda t}$. It is now clear that equation (3) is the formal expression of the conservation hypothesis.

With given technology and given market conditions, equation (3) reflects the technical conditions of production. However, in the long run, when changing prices can make substitution among inputs profitable, equation (3) reflects economic changes, too.

The growth hypothesis is obtained by the profit maximizing condition of energy use, i.e., when the value of the marginal product of energy is equal to the price of energy.

For the production function (1) the equilibrium condition is

$$P\frac{\partial Q}{\partial E} = Pa_3 A_0 K^{a_1} L^{a_2} E^{a_3 - 1} = P_E$$

Where P = Price of output and P_E = Price of energy. Solving for E we obtain

$$E = \frac{\gamma QP}{P_E} \quad (4)$$

This is the derived demand for energy and can be estimated as

$$lnE = \overline{\gamma} + b_1 ln\left(QP\right) - b_2 lnP_E \quad (5)$$

Equation (5) is the formal expression of the growth hypothesis in which the price of energy appears as a factor of demand. It is now clear that the growth hypothesis is the derived demand for energy.

The conservation hypothesis and the growth hypothesis are two expressions of the same economics structure. Therefore, it should not be surprising that some studies find support for one hypothesis and other studies for the other. However, studies in which the price of energy is not included as an independent variable suffer from misspecification and therefore the estimated coefficient of GDP is biased and inconsistent. It is now clear that the real GDP-energy relationship is that expressed in the conservation hypothesis. The growth hypothesis misunderstands the demand for energy function and considers it as the basic GDP-energy relationship.

4. SOME ESTIMATES OF THE GDP-ENERGY NEXUS

On the basis of the above equations, we have estimated the production function and the derived demand for energy using world GDP (Q), world use of energy (E), and energy prices (P) as defined in the Appendix, using time series data.

With time-series data the use of cointegration analysis is appropriate in order to test for the existence of a statistically significant relationship between two or more variables. This is done by testing for the existence of a cointegrated combination of the two series. If such a combination has a low order of integration this can signify an equilibrium relationship between the original series, which are said to be cointegrated. Cointegration analysis is necessary instead of common linear regression methods because if the latter are used on non-stationary time series it might produce spurious results.

Before applying the co-integration analysis, the order of integration of the variables has to be considered using a unit root test. According to the unit root test results, the appropriate method for testing for cointegration will be chosen. If there are only I(1)[3] variables, the Johansen and Juselius (J-J) (1990) method can be used; if the model contains both I(0) and I(1) variables then the autoregressive distributed lag (ARDL) method has to be applied, because the J-J method may produce spurious results (Pesaran and Pesaran, 1997; Pesaran and Shin, 1998; Pesaran et al., 2001; Kripfganz and Schneider, 2019).

The order of integration of the variables is tested by using the Phillips-Perron (P-P) (Phillips and Perron, 1988) unit root test.

The values of the P-P test are presented in Table 1. The null hypothesis (H_0) of a unit root (non-stationarity) is tested against the alternative. H_0 was rejected at 5% level of statistical significance for *ln*E and *ln*P while *ln*Q was found to be non stationary at this level. However, the null hypothesis was rejected for their first difference and it is concluded that the variable *ln*P and *ln*E are I(0) while *ln*Q is I(1). Therefore, the J-J method cannot be used and we conclude that the ARDL method is the appropriate one. However, it is necessary to check that the variables are not I(2) because, in this case, ARDL would produce spurious results (Oteng-Abayie and Frimpong, 2006). As it can be seen from the above table, the variables are either I(0) or I(1).

Before proceeding to the results, we should note that according to the Wald bounds test (Pesaran et al., 2001) and the more recent Kripfganz and Schneider test (2019), we can conclude that there is cointegration among the variables.

3 I(d) denotes the order of the integration of a time series, i.e., it shows the minimum number of differences required to obtain a covariance stationary series.

Table 1: Phillips-Peron unit root test results

Series	Level	First difference
*ln*E	−6.933314*	−22.19735*
*ln*Q	−2.504808	−11.06532*
*ln*P	−7.374259*	−16.29935*

All tests are performed using the 5% level of significance; the null hypothesis of a unit root is tested against the alternative. The asterisk denotes significance at least at the 5% level. Source: Authors' calculations

The results appear of the ARDL method below as R1 and R2. Regression R1 represents the production function and R2 the derived demand for energy. T-statistics are given in parentheses.

$$\Delta lnQ_t = \underset{(3.37)}{-15.36} - \underset{(3.44)}{0.35} ln\,Q_{t-1} + \underset{(0.60)}{0.099} ln\,E_{t-1} + \underset{(3.46)}{0.27} \Delta ln\,E_t + \underset{(3.39)}{0.009}\,T \qquad \text{(R1)}$$

$$\bar{R}^2 = 0.46, \text{obs} = 43$$

$$\Delta lnE_t = \underset{(0.89)}{0.11} - \underset{(2.35)}{0.25} ln\,E_{t-1} + \underset{(0.47)}{0.022}\, lnP_{t-1} + \underset{(23.84)}{0.801}\, lnQ_{t-1} + \underset{(2.78)}{0.69}\, \Delta lnQ_t \qquad \text{(R2)}$$

$$\bar{R}^2 = 0.35, \text{obs} = 43$$

Both regressions have been estimated with a time trend, however, only in the case of R1 time trend was statistically significant.

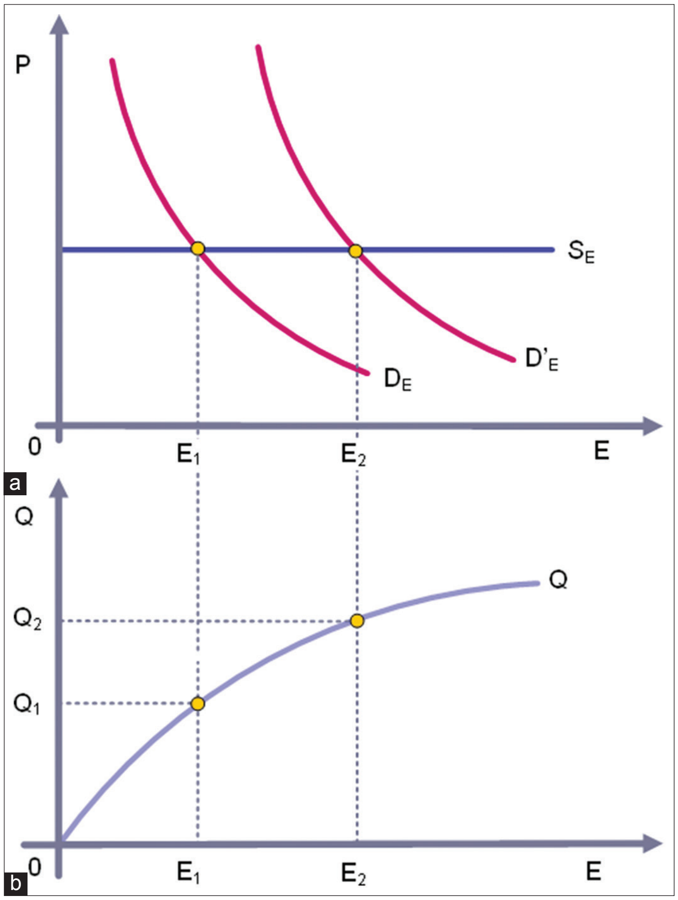
From R1, the long run elasticity for the use of energy with respect to GDP is found to be statistically insignificant while the short-run elasticity (0.27) is statistically significant. This indicates that the long run change in output is not related to the changes in the energy use. The latter can be explained by the technology changes in production, enabling more efficient use of energy, i.e., the same amount of energy produces more and more output though time. Therefore, there is no relationship between the change in output and change in energy use. However, in the short run, where production technology remains unaltered, changes in output require changes in energy use.

Further, from regression R2 it appears that the long-run (0.801) and short-run (0.69) elasticities of GDP with respect to energy use are significant, but the coefficient for energy price is insignificant. The latter result indicates that the use of energy is inelastic with respect to price. In other words, energy, if needed, will be used independently of price. However, it should be noted that the use of energy is not exactly the same thing as the demand for energy, as stocks of energy can be accumulated or depleted without immediately affecting the use of energy. Also, the lack of significance of the price of energy may be attributed to a very elastic supply of energy as shown in Figure 1.

From the above results it is seen that production and energy use are closely related both ways, but the nature of the relationship is different. Q being a function of E is partly technical, as in the production function, and partly economic because of the possibilities of input substitution. E being a function of Q is simply the derived demand for energy. The results also show that there is a time trend present in production but not in energy use. There is no time trend in energy use because the use of energy is uniquely determined by GDP, since there are no other systematic uses of energy. The time trend in GDP shows that there are other factors related to time that affect GDP. Finally, energy use is inelastic with respect to price, as explained.

The following Figure shows the simple model that connects production and energy as it is suggested by the above results.

Figure 1: (a and b) Production function and derived demand for energy



The moving force is the increase in the demand for output from Q_1 to Q_2 (Figure 1b) which increases the use of energy and thus shifts the demand curve from D_E to D'_E. The fact that the demand for energy is found to be inelastic with respect to price can be explained in two ways. First, it may be that the demand is in fact inelastic because energy is absolutely essential in production and cannot be easily substituted by other inputs, at least not in the short run. Second, the supply of energy is very elastic as shown in the Figure. The horizontal line S_E means that the supply of energy is unlimited at the price determined by the oil cartel.

To summarize, we have discussed the nature of the relationship between GDP and energy using economic theory of production and shown that the conservation hypothesis is theoretically valid, while the growth and feedback hypotheses suffer from theoretical setbacks. We then estimated the relationship between GDP, energy use, and energy price, and found them to be in line with theory, i.e., the conservation hypothesis is verified empirically.

5. DISCUSSION

One may wonder why so much research has been devoted to a simple relationship that could be easily identified on the basis on theory. The real reason is the implications that the relationship would have for GDP growth, for conservation policies, and for the environment. Increasing GDP and use of energy have, after a point, negative effects on the environment. The conservation hypothesis implies that if we, as a society, want more goods and services we must use more energy and consequently accept the negative effects of energy consumption on the environment. Similar, but differently stated, is the implication of the growth hypothesis. It says that we if use energy to raise GDP we will also suffer the negative effects on the environment. The implication from the neutrality hypothesis is very different. If GDP and energy use move independently of each other, they may both be sources of problems for the environment although it is very difficult to see how this can happen.

It is important, at this point, to draw attention to a fundamental, albeit often forgotten, fact, namely that GDP growth is needed for the consumption needs of an increasing population, or for a higher level of consumption of a given population, or for both. A simple exposition of this fact is provided by the increasing ecological deficit of the world but also by the diminishing biocapacity per capita figure, which happens despite technological change driving up the total biocapacity of the earth (Global Footprint Network, 2018; Lin et al., 2018).[4] Therefore, the actual factors causing environmental negative results are population growth and/or increases in per capita consumption. Of course, acknowledging these two critical factors does not imply that conservation policies and more efficient production technologies are useless.

6. CONCLUSION

The conclusions reached by our analysis can be briefly stated as follows:

1. From the four hypotheses usually stated in the examination of the GDP-energy nexus, only the conservation hypothesis is directly supported by economic theory. The growth hypothesis as usually stated is not valid because there is no direct causal relationship running from energy to GDP. The relationship between these two variables, namely energy and GDP, is indirect via the market for energy and it can be understood as the derived demand for energy. The feedback hypothesis suffers from the same misspecification as the growth hypothesis because it contains the latter. The neutrality hypothesis has absolutely no basis in economic theory
2. The data for the world economy support the conservation hypothesis. Also, the demand for energy depends on the quantity of output produced but not on the price of energy. The lack of significance of the price of energy can be attributed either to inelastic demand or to very elastic supply
3. To the extent that the GDP-energy use relationship is relevant for the environmental problems, it is important to bear in mind that behind the necessity for GDP growth is hiding the increasing world population and the increasing per capita consumption.

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4 It should be noted that the ecological footprint does not take into account the depletion of nonrenewable resources, hence the figures provide an incomplete (lower) estimate of the effect of economic activity on future resource availability.

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APPENDIX: DATA SOURCES

Energy use	World Bank. Indicator: EG.USE.PCAP.KG.OE. Indicator name: "Energy use (kg of oil equivalent per capita)" Note from source: Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport Link: https://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE Authors note: We derived the global figure by using the World Bank Population data https://data.worldbank.org/indicator/SP.POP.TOTL
Price of energy	World Bank Commodity Price Data (The pink sheet). Series: Energy. Annual indices (real), 2010=100, 1960 to present, real 2010 US dollars. March 2018 edition (accessed 26 March, 2018) Available from: http://www.worldbank.org/en/research/commodity-markets Direct link to the data: http://pubdocs.worldbank.org/en/226371486076391711/CMO-Historical-Data-Annual.xlsx
Gross world product	World Bank. Indicator: NY.GDP.MKTP.KD. Indicator name: "GDP (constant 2010 US$)". Data cover the range 1960-2016 (accessed March 5, 2018) Note from source: GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2010 U.S. dollars. Dollar figures for GDP are converted from domestic currencies using 2010 official exchange rates. For a few countries where the official exchange rate does not reflect the rate effectively applied to actual foreign exchange transactions, an alternative conversion factor is used