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Transport Intensity and Energy Efficiency: Analysis of Policy Implications of Coupling and Decoupling

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1. Introduction

Economic growth based on use of non renewable energy constitutes a serious problem because of, especially, negative environmental externalities. Growth of energy consumption and gas emissions are the principal negative impacts of these modes of development. However, the sustainable development requires modes of development which demand few of energy and produce few of pollutant gas. Literature has interested of this problematic in an aggregate or disaggregate contexts. The first is concerning the relationship between economic growth, domestic energy consumption and gas emissions. The second is corresponding to the same relationship but per economic sector. Industry and transport sectors are more studied because of their important link with economic and environmental spheres. They have an important contribution in economic growth but they are responsible of several environmental externalities.

The transport is one of the major activities which consume more energy and produce gas pollutants. Majority of freight and passengers is transported by road mode which is considered an important source of fossil fuels consumption and CO_2 emissions. In order to make transport sector more sustainable, some strategies should be elaborated to reduce its energy consumption and gas emissions. In other terms, governments should apply a set of instruments, such as economic, fiscal, regulatory and technological instruments, to control driving factors of transport-related energy consumption and gas emissions.

Before any strategy, it's necessary to evaluate the sustainability degree of transport sector. Sustainable transport literature give us several indicators through them it's possible to measure energy demand and gas pollutants production associated to transport activity. Examples include transport intensity, transport energy intensity, transport energy emission

intensity, vehicle intensity and vehicle energy intensity. Other indicators, such as modal mix (road, rail, air and water shares), energy mix for every mode (gasoline, diesel, liquefied petroleum gas (LPG), electricity or other fuel types, such as bio-carburant), rate of motorization, transport energy consumption share and annual growth of Vehicle Park are also used to diagnostic sustainability from transport sector. Determine the driving factors of transport-related energy consumption and pollutants gas emission growth is a one of main phases. It helps to choice the optimal strategy which corresponds to every responsible factor. With all types of intensities which are evoked, economic, demographic, urban and technological factors are taken as the main factors which can influence energy consumption and so gas emissions of transport sector. Moreover, examples of influencing factors include also average travelling distance, vehicle types share (personal cars, bus, heavy and light trucks), average vehicle age, driving condition, urbanization, urbanized kilometers and national road network.

More existing methods has presented by sustainable transport literature to examine the relationship between economic growth, transport activity and environmental impacts and to determine the driving factors. We distinguish three principal approaches: first, causality approach that based on time series methods, Kuznets Environmental Curve model and third, decomposing analysis method.

The aim of this chapter is to analyze the sustainability of transport activity especially through the energy efficiency indicator and different associated influencing factors. To this end, the rest of the chapter is structured as followed: section 2 presents an overview of works which have focused on transport energy efficiency. Section 3 describes methodologies applied to study energy consumption from transport sector with more interesting to decomposing analysis. Section 4 presents the driving factors and policy options to ameliorate transport energy efficiency. Section 5 concludes.

2. Transport energy saving: literature review

Transport activity is strongly related to economic activities. Traffics realized permit to link markets of production and consumption through the satisfaction of persons and freight transport demand. However, transport services supply is often associated to many problems that affect economy, society and environment. Negative environmental externalities appear especially if economic activity and transport services are more coupled. In this context, *transport intensity* is often used to measure transport demand and to analyze negative consequences of the coupling relationship between economic growth and transport activity. It's defined as the ratio of gross mass movement to Gross Domestic Production (GDP). It can be measured separately for the passenger services (passenger kilometres, *pkm*) and freight (ton kilometres, *tkm*). Close relationship between the growth in transport and economic growth implied an increase of transport intensity and so an increase of transport-related energy consumption and gas emissions. Transport-related energy consumption is currently measured in the literature through *energy intensity* which calculated by the ratio of transport energy consumption to transport services supply. It indicates the demand of energy per unit

of transport service (*tkm* or *pkm*). Amelioration of energy efficiency from transport sector implies reduction of energy intensity and so saving energy consumption for the sector.

Transport energy intensity has studied in several contexts. Examples include studies which interest to the relationship between economic growth and transport activity and transport energy consumption. This analyze is defined in two approaches. Firstly, the economic approach which aims to study the causality relationship between them and to analyse the expenditure in energy consumption. Secondly, the ecologic approach which aims to study the correlation between them in order to determine the coupling phenomena between them and to measure and analyse energy consumption and gas emissions. Moreover, examples include studies which decomposing the intensities in order to determine the influencing factors of the transport-related energy consumption growth.

More existing studies have focused on the causality and cointegration relationship between transport energy consumption, transport activity and some main factors. Their main objective is to determine the time tendencies of their trends, the sense of their causality, the degree of their cointegration and then the coupling problem (Meersman et Van De Voorde, 1999; Kulshreshtha et al., 1999; Stead, 2001; Banister and Stead, 2003; Léonardi et Baumgartner, 2004; Tanczos et Torok, 2007).

Recently, Akinboade, Ziramba and Kumo (2008) have used the co-integration techniques in order to analyze the long-run relationship among the variables which explicating the aggregate gasoline demand function over the period 1978-2005 in South Africa. The results confirm the existence of a co-integrating relationship. The estimation of the price and income elasticities of gasoline demand serves to develop appropriate energy policy. The estimated elasticities show that gasoline demand in South Africa is price and income inelastic. The important policy implication is the unreliability of the public transport system in South Africa. Yaobin (2009) explains cointegration relationship between transport energy consumption growth, population growth, economic growth and urbanization process for china over the period 1978 -2008. The results show a unidirectional Granger causality running from urbanization to energy consumption both in the long and short run. Lu, Lewis and Lin (2009) have estimated the development trends of the number of motor vehicles, vehicular energy consumption and CO_2 emissions in Taiwan during 2007-2025. They have adopted simulation of different economic growth scenarios in order to explore the influence of economic growth on energy consumption.

Pongthanaisawan and Sorapipatana (2010) have analyzed the relationship between motorcycle and car ownerships and level of economic development for the case of Thailand. They study the impacts of this relationship on fuel consumption and greenhouse gas emissions. Using semi-parametric techniques, the authors have shown that economic development affects the ownership of private vehicles which and so fuel consumption and gas emissions. The important conclusion of their study is that the amelioration of public transport system leads to reducing the traffic mobility of private vehicles, promotion of the vehicle efficiency and so reducing fuel consumption and gas emissions. Yan and Crookes (2010) have forecasted the future trends of energy demand of road vehicle and emissions

under various strategies for reducing the impacts of china's road vehicles on energy resources and environment. These strategies have concerned on the fuel economy regulation, alternative fuels and vehicles, public and non-motorized transport and economic incentives. Rudra (2010) explores the causality relationship between transport infrastructure, energy consumption and economic growth in India over the period 1970-2007. He finds a unidirectional causality from transport infrastructure to energy consumption. This results mains that energy and transportation policies must be recognized. Marshall *et al.* (2011) explores the causal relationship between residential location and vehicle miles of travel, energy consumption and CO2 emissions in Chicago metropolitan area over the period 2007 - 2008. Reinhard *et al.* (2011) concluded that urban energy planning and urbanization management are strongly linked and must be coordinated to lead to sustainable energy development.

In order to study transport-related energy consumption, majority of works have used the decomposition method. It's one of the most effective applied tools used to investigate the factors influencing energy consumption and its environmental impacts. The intensity decomposition method dates back to studies undertaken in the 1980s. It has known an expansion with works interesting to evaluation of aggregate energy consumption caused especially by the preceding energy crisis. It had evoked especially in the industrial context (Howarth *et al.*, 1991, Parck 1992). However, in the 1990s and 2000s this technique has been generalized to be used and applied to other sectors such as transport sector. The main objective of this method is to identifying factors that influence directly or indirectly energy consumption. One of the important decomposition of energy efficiency is which had proposed by Kaya (1989) in the context of energy economy. Kolbs and Waker (1995) have used decomposition method to find determinants of energy consumption and greenhouse gas emissions[1].

For the case of transport, several studies have been interested to decomposing energy consumption in transport sector in order to show the contribution of traffic in pollution. Schipper, Scholl and Price (1997) have decomposed energy intensity on three factors; transport activity (tone kilometre), structure of transport (types of modals) and intensity (energy used per unit of transport). They have concluded that best energy efficiency cannot compensate increasing of transport and modal share of road transport. Kveiborg and Fosgerau (2004) have decomposed the energy intensity of road transport for Denmark along the period 1981-1997. They have found that energy efficiency has been ameliorated by reducing of industrial production share and travelling distance through implantation of logistic platforms. Steer Davies Gleave (2003) have concluded, for the case of Germany, France, Spain, Italy and England during the period 1970-2000, that reducing of the road transport share has ameliorated the energy efficiency for the countries group. Steenhof *et al.* (2006) have used decomposition of energy intensity in order to examine the determinants of GES caused by freight transport in Canada. They have concluded that technical progress is inadequate solution if share of freight road transport increase for USA. Tanczos and Torok

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[1] Liu and Ang (2007) have exposed a large majority of studies which used the method of intensity decomposition.

(2007) have studied the relationship between road transport, energy consumption and CO_2 emissions for the case of Autriche. Sorrell *et al.* (2009) have found for the case of England during the period 1989-2004 that increasing of vehicle transportation capacity and reducing of vehicle average energy consumption have ameliorated the energy efficiency. Niovi *et al.* (2010) estimates the effect of the spatial structure of the economy and the degree of spatial concentration of activities on fuel demand by using decomposition analysis. The results show that urban density increases fuel consumption.

3. Methodologies used for study of transport energy efficiency

3.1. Causality and cointegration relationship between transport energy consumption, transport activity and economic growth

An open question for relationship between transport activity, economic growth and environmental effects is the correlation between their trends. Negative environmental effect will be increasing when correlation between economic growth and transport is largely important. Exam of this correlation is important in so far as it provides a several instruments to elaborate an efficient transport policy. In literature, a large majority of studies have interested to determine separately correlation between first, transport activity and economic growth (coupling problem) and secondly transport activity and energy consumption and gas emission. In this chapter we propose a demarche which treats simultaneously both the tow problems. We attempt to include in our analysis dimension of sustainable transport for which actual policies transport have been taken.

In this context, a large number of studies have interested to the problem of coupling. An important number of institutional reports had elaborated like REDEFINE (1999) and SPRITE (2000) in Europe. Otherwise, several scientific studies have been elaborated in two directions. First, studies which estimate relationships between transport of passengers or goods and economic growth using previous traffic models (Meersman and Van De Voodre (1999) for the case of Belgium and Klushershtha and al. (1999) for India). Second, studies which have interested to aggregated indicators in order to estimate the coupling (Baum (2000) and Baum and Kurte (2002) have used the intensity of road transport to measure coupling for the case of Germany and Stead (2001) for the case of Europe).

In order to study the relationship between transport energy consumption, transport activity and economic growth, we should test the stationary of the series. To this end tests which are common use are Augmented Dickey-Fuller (ADF) tests (Dickey and Fuller, 1979) and Phillips-Perron (PP) tests (Phillips and Perron, 1988). The objective is to know if the series are stationary in levels or in some order of differentiation. If the integration of the two series is of the same order, we should test whether the two series are cointegrated over the same period. Analyze of cointegration between the series is often realized through method of Johansen (1988).

The Trace and maximum eigenvalue test provide us the information concerning the presence or nor of the cointegration. Consequently, we can estimate a vector error correction model (VECM) that incorporates variables and variation levels for information on the speed

of adjustment to equilibrium. Engle and Granger (1987) showed that if two series are cointegrated, the VECM for the two series can be written as follows:

$$\Delta y_t = \alpha + \sum_{i=1}^{k} \beta_i \Delta y_{t-i} + \sum_{i=1}^{k} \lambda_i \Delta x_{t-i} + \eta ECT_{t-1} + \mu_{1t} \tag{1}$$

$$\Delta x_t = \alpha + \sum_{i=1}^{k} \beta_i \Delta x_{t-1} + \sum_{i=1}^{k} \lambda_i \Delta y_{t-i} + \eta ECT_{t-1} + \mu_{2t} \tag{2}$$

In Eqs. (1) and (2), PCTS and PCGDP (or per capita transport energy consumption PCTEC) represent per capita transport services and per capita GDP, respectively, whereas ΔPCTS and ΔPCGDP are the differences in these variables that capture their short-run disturbances and k is the number of lags. μ_{1t} and μ_{2t} are the error terms. *ECT* is the error correction term that measures the magnitude of past disequilibrium. The coefficient η represents the deviation of the dependent variables from the long-run equilibrium. The significance of the explanatory variables coefficient (λ_i and β_i) confirms the presence of short-run causality.

The robustness of the VECM is evaluated by using the normality residual test of Jarque-Bera, the Portmanteau auto-correlation test, the autocorrelation LM test, and the White homoscedasticity test. All these tests help us to accept or not the null hypothesis of no serial correlation. The normality residual test statistics of Jarque-Bera indicate if we accept or not the null hypothesis of normality of the residuals. The joint test statistics of the White homoscedasticity test with the no cross terms indicates if we accept or not the null hypothesis of non-heteroscadasticity at a 5% confidence level. If the model passes all the tests successfully, the estimation of the VECM gives the cointegrating vector.

After tests of cointegration, Granger causality test should be applied in order to exam the causality relationship between series. The sources of causation can be identified from the significance test of independent variables coefficients in the VECM. Regarding the causality of the short- run, we can test the nullity of the parameters associated with independent variables in each equation of VECM using the χ^2 -Wald statistics. The Causality long-run can be tested by the significance of the speed of adjustment. We use the t-statistics on the coefficients of the ECT indicate the significance of the long-run causal effects. The test give us the values of the speed of adjustment coefficients in the two equations of the PCTS and PCGDP which indicate if any deviation of the balance of long run of the value of the growth rate of the income tends to accelerate to adjust themselves with the shock and to return on its level of balance in a way faster than the rate of growth of the transport services. The validation of the first equation makes it possible to affirm that it is better to explain the GDP by the transport services than the transport services by the income. After testing cointegration and causality between transport activity evolution and economic growth, we can conclude if the two series are coupled or uncoupled.

The same procedure can be applied between transport activity and transport energy in order to determine the relationship between them and so to conclude if the transport sector is sustainable or not.

3.2. Relationship between transport activity and transport energy consumption : estimation of EKC

The genesis of the EKC can be traced back to Kuznets (1955), who originally discussed the relationship between economic growth and income inequity and suggested when per capita increase, income inequity increases also at first stage but after a certain level, starts decreases. This relationship follows an inverted-U curve and has is known as the Kuznets curve. Since the early 1990s, this curve measurement has progressed to become more used in analysis of relationship between economic development and environment quality (Grossman and Krueger, 1991; Bandyopadhyay, 1992; Panayotou, 1997).

Sustainable transportation system literature has more focused on negative environmental impacts caused by transport activity. Increase of traffic leads to increase of energy consumption and so degradation of air quality. Several factors can explain the increase of traffic, such as the economic growth, growth of population, urbanization, change in the lifestyles, increase of road infrastructures, etc. All these factors can lead to increase of passenger and freight mobility (Carlsson-Kanyama and Lindén, 1999; Ramanathan, 2000; Storchmann, 2005; Van Dender, 2009).

In the EKC literature there is a few studies which focus on the relationship between transport-related energy consumption and gas emissions and economic growth. Among these studies, we can quote the study elaborated by Cole et al. (1997) which examine the between per capita income and local air pollutants, and between energy consumption from transport sector and traffic for European countries over the period 1970-1992. They conclude that EKC relationship exist for local air pollutants from transport. Hilton and Levinson (1998) test the existence of EKC for plumb emissions from transport sector for 48 countries during 20 years. They find that their relationship with economic growth supports an EKC and explain their evolution by the increase of the private cars use. Two types of factors are mentioned by the authors: first, the pollutant fuel intensity (pollutant content per fuel type) and second, vehicle fuel intensity (energy efficient vehicle). Khan (1998) shows the existing of an urban EKC (UEKC) for hydrocarbon emissions from urban traffic in California State. He explains the increase of these emissions through the growth of personal mobility per private cars and its related fuel consumption.

Recently, Rupasingha et al. (2004) examine the urban polluting emissions of 3029 American counties using the EKC model and urban size and daily mobility as important determinants. Liddle (2004) examines the EKC relationship between per capita road energy consumption and per capita income, using IEA statistics. They conclude that hypothesis of an inverted-U curve are not existed and then EKC can't be proved. Tanishita (2006) examines the existing of the EKC for energy intensity from passenger transportation and concerning a set of data during the period 1980-1995. He finds that the relationship between the energy intensity of private and public transportation and the per capita Gross Regional Product (GRP) corresponds to an inverted U-shape of the EKC.

In the EKC literature, many functional form of EKC model are presented. Some studies consider only a cubic equation of income per capita as those of Grossman and Krueger (1991,

1995) and Harbaugh et al. (2002), or a quadratic equation, such as studies of Selden and Song (1994), Holtz-Heakin and Selden (1995), and Stern et al., (1996). Other econometric studies estimate several empirical models (linear, quadratic, cubic). The significance of the cube per capita income is based on the assumption of an N relation. Moreover, two principal types of curves coexist in the EKC literature. The first is the "diachronic" one which used with times series and aims to study the evolution of transport sector energy consumption comparatively with the evolution of income. However, the second is the "synchronic" one which used with cross-section data. The quadratic functional form of EKC is assuming the traditional EKC functional form. Then, we present the following regression model to describe the interaction between economic growth and transport sector energy consumption:

$$\ln(\text{E}) = \alpha_0 + \alpha_1 \ln(PCGDP) + \alpha_2 \left[\ln(PCGDP)^2 \right] \tag{3}$$

were E refers to energy consumption from transport activity and treated as dependent variable, $PCGDP$ refers to per capita gross domestic production (PPP) and treated as independent variable and ln indicates natural logarithmic transformation. If the regression coefficient α_2 is negative, functional form of regression model corresponds to the standard EKC model.

The inverted-U relationship implies that energy consumption is reduced and so environmental quality improves beyond a certain threshold of income per capita. Lind and Mehlum (2007) present the basic properties that must satisfy the U relation. Their main idea insists that the U- inverted should have a positive slope at the beginning of the turning point and negative thereafter. This condition ensures that the endpoint is in the range of data. This condition can be written as follows:

$$\alpha_1 + 2\alpha_2 \ln PCGDP_{Min} \geq 0 \tag{4}$$

$$\alpha_1 + 2\alpha_2 \ln PCGDP_{Max} \leq 0 \tag{5}$$

where $\ln PCGDP_{Min}$ and $\ln PCGDP_{Max}$ are, respectively, the minimal and maximum values of the variable $\ln PCGDP$.

3.3. Methodology of decomposition analysis

In order to determine coupling relationship between increase of transport activity and economic growth and also transport energy consumption between, the analysis based on time series models and EKC models are considered as an aggregated analysis which not provides an explanation of the sources of coupling problem and growth of energy consumption. To this end, more existing studies have explained this relationship by decomposing aggregated variables of transport demand (transport intensity) and transport energy demand (transport energy intensity) into coupling and decoupling factors. The main objective of this approach is to identify the main factors that influence energy consumption of the transport sector, especially of road mode, to evaluate their impacts and to propose

some solutions some sustainable policy options to reduce energy intensity. Majority of studies have interested on consumption of fossil fuels namely, diesel and gasoline. Ang and Zhang (2000) have proposed a review of literature for this decomposition analysis. Banister and Stead (2002) have studied the energy efficiency and economic efficiency of transport sector for European countries. They have found that passengers-kilometer is not a driving factor for nine European countries; tonne-kilometer is a driving factor of energy transport efficiency growth for six countries and of energy transport efficiency deterioration for eight countries. Zhang et al. (2011) have decomposed the energy consumption in Chinese transportation sector and have found that the transportation activity effect is the important contributor to increase energy consumption in the transportation sector and the energy intensity effect drivers significantly the decrease of energy consumption.

Technique of energy decomposition is largely useful in sustainable transport studies. Several methods of decomposition have been proposed in the literature such as the refined Laspeyres techniques (Lin *et al.*, 2008), the Arithmetic Mean Divisia Index (AMDI) and the Logarithmic Mean Divisia Index (LMDI) techniques (Ang, 2005; Liu *et al.*, 2007, Hatzigeorgiou *et al.*, 2008; Timilsina and Shrestha, 2009).

In this section we derive the methodology to decompose transport sector energy consumption growth to the influencing factors, such as demographic, economic and urban characteristics. Examples include vehicle fuel intensity, vehicles intensity, urbanization, per capita GDP, motorization, road network length, modal mix, fuel mix and more other factors which will be discussed in the section 4.

Transport energy intensity in year t (TEI_t), can be expressed as:

$$TEI_t = \sum_{it} TEI_{ijt} \tag{6}$$

where subscripts i, j and t refer to fuel type (e.g., diesel, gasoline and GPL), transport mode (e.g., road, rail, air and water) and year, respectively. In order to decomposing transport energy intensity into the contribution factors, several formulations can be proposed according the factors integrated in the decomposition and the transport services type (freight transport or passenger transport). It should be note that choice of potential factors is based on availability of time series data and the causal relationship test. For example Eq. 1 can be expressed as

$$TEI_{ijt} = \frac{TE_{ijt}}{GDP_t} = \frac{TE_{ijt}}{TE_{it}} \times \frac{TE_{it}}{TS_{it}} \times \frac{TS_{it}}{GDP_t} \times \frac{GDP_t}{RV_{it}} \times \frac{RV_{it}}{POP_t} \tag{7}$$

Eq.2 can also be rewritten as

$$TEI_{ijt} = \sum_{ijt} MM_{jt} \times EI_{it} \times TI_{it} \times VI_{it} \times M_{it} \tag{8}$$

were *MM* refers to modal mix which indicates the share of fuel consumption by a mode in total transport energy consumption, *EI* refers to transportation energy intensity per mode

which indicated the demand of energy to produce unit of transport services per mode, *TI* represents transport intensity per mode which indicates the demand of modal transport services to produce unit of GDP, *VI* refers to vehicle intensity and measures the demand of vehicles by mode to produce unit of GDP and *M* refers to rate of motorization. The change in these factors summarizes their direct and indirect impacts on change in transport energy intensity. The indirect impacts pass through the influence of demographic, economic and urban characteristics on transport energy intensity.

Using LMDI method because their advantages comparatively to Laspeyres techniques as shown by (Ang, 2004)[2], change in transport energy intensity $\left(\Delta TEI_{ijt} \right)$ between two periods can be attributed to effects of:

- Change in modal mix $\left(\Delta MM_{ijt} \right)$ named effect coefficient MM_{eff} ,

- Change in vehicle intensity $\left(\Delta EI_{ijt} \right)$ named effect coefficient EI_{eff} ,

- Change in economic activity $\left(\Delta TI_{ijt} \right)$ named effect coefficient TI_{eff} ,

- Change in urbanized kilometers $\left(\Delta VI_{ijt} \right)$ named effect coefficient VI_{eff} ,

- Change in national road network $\left(\Delta M_{ijt} \right)$ named effect coefficient M_{eff} ,

Consequently,

$$\Delta TEI_{ijt} \equiv RTE(T) - RTE(0) \equiv MM_{eff} + EI_{eff} + TI_{eff} + VI_{eff} + M_{eff} \tag{9}$$

Then, effects can be calculated for example for MM_{eff} as:

$$\Delta TEI_{ijt} \equiv \left[TEI(T) - RTE(0) \right] \ln \left[MM(T) / MM(0) \right] / \left[TEI(T) - RTE(0) \right] \tag{10}$$

Growth of transport-related energy intensity can be analyzed among its sensibility to changes in the named direct factors.

4. Driving factors of transport energy efficiency and policy options

Before presentation of decomposition methodology, we present and discuss some potential factors which have impacts on transport energy intensity. This is following by policy options to reduce transport energy use.

4.1. Driving factors of transport energy intensity change

Several factors contribute to change in energy intensity of transport sector. Examples include:

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[2] Contrarily to Laspersey method, the advantages of LMDI method are, for example, the residual-free decomposition and the accommodation of the occurrence of zero values in the data set to small positive constant.

Causality relationship analysis		
Study	Variables	Result
Léonardi and Baumgartner, 2004	Transport energy efficiency and CO_2 emission efficiency in road freight transport. transport energy efficiency and efficiency of vehicle usage and	$r^2 = 0.42$ $r^2 = 0.39$
Mraihi and Hourabi, 2011	Energy intensity in road freight transport and transport intensity	Existence of a long-term relationship between transport intensity and energy intensity in road freight transport. Elasticity = 0.71
Environmental Curve of Kuznets		
Study	Variables	The estimated turning point
Meuni and Pouyann, 2009	Polluting emission due to the urban daily mobility (quadratic form).	Existence of an inverted-U form is significant for CO and NOx: $23.739 at 2000 constant price. $27.433 at 2000 constant price.
Ubaidillah, 2011	Trend of CO emission from road transport.	Existence of an inverted-U shape function of income for road transport: $21,402 at 2000 constant price.
Decomposing analysis method		
Study	Variables	Results
Timilsina and Shrestha, 2009	Change in CO_2 emission from transport for Asian countries. Driving factors: CO_2 intensity of a fuel, share of a fuel in a transportation mode, share of fuel consumption by a mode in total transport sector energy consumption, transportation energy intensity, economic activity as captured by per capita GDP and population.	Transport energy efficiency is considering an important driving factor of emission growth for 7 Asian countries. Economic growth and population growth are the critical factors in the growth of transportation sector CO2 emissions in all countries except Mongolia.
Banister and Stead, 2002	Change in transport energy intensity for European country. Driving factors: passengers-kilometer and tones-kilometer.	Pass-km is not driving factor for nine European countries (with an impact of 10%). Tones-km is a driving factor of energy transport efficiency growth for six European countries (with an impact more than 10%) and of energy transport efficiency deterioration for eight countries (with an impact lower than 10%.

Table 1. Examples of empirical results of transport energy efficiency analysis

- *Transport intensity per mode*: transport intensity is measured by the ratio of transport services to the GDP. Transport services can refer to the number of passengers/kilometer for passenger transport and tones/ kilometer for freight transport. The transport intensity measures the transport demand necessary to create a unit of GDP. Coupling between economic growth and transport activity development leads to the increase of transport intensity. The transport energy consumption, as an externality of coupling relationship, depends largely on the growth of this demand. However, modal transport energy consumptions are different and the road mode may the important consumer of energy. Then, transport energy intensity depends on modal transport intensity. The modal mix of transport services indicates the mode that is more used and if the transport policy approved by public authorities helps to shifting over to the mode which consumes less of energy.

- *Modal energy intensity*: energy intensity is measured by the ratio of energy consumption per mode to transport services per mode. It measures the amount of energy necessary to achieve a transport services output. It can be calculated from each mode and so illustrates the evolution of their fuel consumption shares. The analysis of this indicator needs also the analysis of the modal mix for energy consumption. In this context fuel prices, fuel taxes, clean fuel subsidizes, clean vehicles subsidizes and many other economic, fiscal and regulatory factors contribute to energy intensity changes. Motor gasoline and diesel are more used especially in road mode and the switching to renewable fuels can reduce the gas emissions, especially, because of the more use of.

- *Economic structure*: economic structure growth could be one of important potential driving factors of transport energy consumption growth. Shares contribution of sectors influence the use of transport services. Then, change in economic structure which place services sector in first place could be one of the main factors which could reduce transport energy intensity. However, economic growth based on industrial and agriculture sectors improve the use of transport services and lead to growth of energy intensity.

- *Vehicle fuel intensity*: it measures the average demand of fuel per unit of vehicle. There is a great deal of interaction between road transport-related energy consumption and efficient energy use of vehicles. Amelioration of fuel consumption efficiency of vehicle can be realised through vehicle design and technology. Vehicle fuel intensity depend on fuel prices, taxes imposed to fossil fuels use, subsidizes given to clean fuel use, growth of clean vehicles use and comportment of driving behaviour.

- *Vehicles intensity*: it measures the demand of vehicles necessary to produce one unit of GDP or of transport services output. Transport energy demand is closely link to national vehicle park. It indicated if the economic growth needs more trucks for freight transport and personal cars for passenger transport. Travelling distance is also depending on vehicle demand. Several factors can be contributing to change of vehicle intensity, such as particular credits for ownership cars, leasing credits for road freight vehicles, and other fiscal and financial facilities which contribute to the annual increase of injected supplementary vehicles.

- *Economic and motorization growths*: the evolution of per capita GDP (based on purchasing power parity (PPP)) influence the motorization level through the buying power.

Increase of buying power leads to the growth of private vehicles number and so of personal mobility. Then, transport energy intensity is linking to the level of personal motorization. Rapid growth of both motorization and travelling distance improve energy consumption and gas emission of transport sector. Moreover, increase of motorization in urban areas leads to more urban congestion with which the energy intensity will be reinforced for urban transportation.

- *Demographic and urbanisation growths*: growth of population, especially in urban areas, has an influence on transport energy consumption. If the demographic change is going through a growth of urbanisation, urban density tends to growing at a higher average annual growth rate. The percentage of urbanized kilometres will increases[3] because of growth of urban density and spatial distribution of households and activities behind the urban roads. It should be note, that in urban areas, urban planning and transport planning favourite the accessibility of urban activities by roads more than other modes. Then with the less supply of rail mode, the evolution of urbanized kilometres and road transport-related energy consumption may be high correlated (Newman and Kenworthy, 1989).

- *National road network*: if the cities and activities are more accessible by road infrastructures, this encourages using of road mode. The length of national road network (local, regional, national and express highway) can explain the growth of road transport-related energy demand. Public choices in term of transport investments repartition contribute significantly to the length of road network and so to use of road mode.

4.2. Policy options

In this section we derive some policy options which can reduce energy intensity from transport sector and so ameliorate the energy efficiency of transport activity. These policy options aim to reduce coupling factors effects and improve decoupling factors effects. As we have showed, from decomposing analysis, it become possible to determinate the principal contributors of transport energy consumption growth, named driving factors. The analysis of critical factors trends helps to identify the instruments to reduce their effects and so to save energy. From these instruments, it will be possible to elaborate some energy sustainable policies for transport sector. Examples of instruments include technological, technical, regulatory, fiscal and economic instruments.

Decoupling the transport energy consumption from economic growth is one of the important solutions if the economic growth is identified as a driving factor. Several practices are suggested in this context and depend on the type of decoupling (relative or absolute decoupling)[4]. Then many policy options are available to ameliorate the transport sector energy efficiency:

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[3] Urbanized kilometers measure the concentration of population behind the urban road network.

[4] Decoupling is said absolute if negative externalities are stable or decreasing simultaneously with an economic growth. However, it said relative if the growth of negative externalities is less than of economic activity.

Logistic solutions, such as relocation of production units, multimodality, intermodality, optimization of the entire transportation chain from origins to final delivery and rescheduling of transport operations for companies are some examples of instruments which aim to reduce the travelling distances but not transported tons.

Modal shifting is also a decoupling instrument which aims to improve the demand of less energy-intensive modes of transport. In the large majority of countries, road transport is the predominant mode. It has often the important share in transport sector fuel consumption. To reduce its energy intensity, authority should shift over to rail mode. To this end some tools should be applied, for examples, reinforcing of rail infrastructures, the amelioration of services quality (availability, speed, regularity, tariffs, security, accessibility) and subsidizes for users of rail services.

Economic structure change which increases the share of service sector in the GDP can reduce transport intensity and so ameliorate the energy efficiency of transport sector. Volume of physical production and its movements from production market to consumption market have a determining influence on travel distances. When economic growth is driving especially by tertiary sector and trucks with high transportation capacities are used for freight transport, travels can be reduced and energy necessary to satisfying the demand of economic growth in term of transportation can be also reduced.

Transport planning can be reduce personal mobility and reduce distances especially in urban areas. It should be adopted by local authorities in order to make sustainable their transport system. Shifting over public transport is one of the important solutions of urban transport planning. Ameliorating supply and quality of public passengers transport could reduce personal motorization. Developing of public transport network by extension of public transport lines and through integration of private investment could be improving the public transportation. Moreover, revising the spatial distribution of households and activities in order to reduce travels can be deteriorating the urban density, the urbanized kilometers number and so road transport-related energy consumption in urban areas. New equity in term of spatial repartition of activities between all cities could reduce the concentration of populations and economic activities in megacities and so urbanized kilometers.

Fiscal and economic instruments could ameliorate the transport energy efficiency. They can be use to encourage the shifting over to energy efficient mode and the switching to clean fuels. In order to ameliorating the vehicle fuel efficiency and so reducing the vehicle fuel intensity, governments can impose some fiscal instruments. For examples, taxation of fossils fuels for personal cars use can increase the personal fuel expenditures and so encouraging the substitution of collective transportation to individual transportation. In addition, fossil fuel taxes for road freight transport could encourage the companies to promote the use of vehicle with high capacities transportation and less energy consumption. These taxes could be applied along with subsidies given for users of renewable energy. Government can also apply economic instruments, such as the increase of diesel and gasoline prices in order to substitute of the clean fuels to fossil fuels.

Regulatory instruments can be also help to improve the transport sector energy efficiency. Restrictions of older road vehicles importation and encouragements of vehicle fuel economy standard can be use as successful tools to reduce energy intensity. Additionally, control of leasing credits given to road freight companies and particular credits for personal cars could reduce road vehicles demand and improve public transport demand.

Technological instruments have shown their positive impacts on vehicle energy efficiency. Research and development have given several technologies which aim to reduce energy consumption of vehicles. Fuel economy can be realized by ameliorating of energy efficiency of drive train. So, new technologies which applied on the power of vehicle's engine could ameliorate the engine efficiency. Moreover, fuel economy increase also with reducing of the amount of energy necessary to move the vehicle. New technologies used to reduce vehicle weight and rolling resistance permit to increase energy efficiency. We should be note that these technologies are more accessible for developed countries and more expansive for developing countries.

5. Conclusion

As stated at the beginning of this chapter, the relationship between economic growth, transport activity and energy consumption is analyzed by more existing studies. In this chapter, majority of methodologies used to study energy efficiency for transport sector has been examined. From the sustainable transport point of view, there are large set of factors which influence transport sector energy consumption. All these factors are defined in the contexts of coupling and decoupling relationship between transport development and economic growth.

Ameliorating of transport sector energy efficiency depends on economic, urban, technological and fiscal factors. Decisions in land use planning and transport planning, prices and quality of fuels, taxes and subsidizes and investments on new technologies have a significant impacts on control of energy efficiency from transport sector and their environmental effects. However, in developing countries, improving the energy efficiency in transport sector requires more attention by government authorities, investors and civil society. Policymakers in these countries give more importance to transport accessibility to population and search to satisfying the economic growth in term of freight transport without any policy of energy economy.

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