DTU Library

Technology priorities for transport in Asia: assessment of economy-wide CO2 emissions reduction for Lebanon

Dhar, Subash; Marpaung, Charles O. P.

Published in:
Climatic Change

Link to article, DOI:
10.1007/s10584-014-1309-7

Publication date:
2015

Document Version
Peer reviewed version

Technology priorities for transport in Asia: Assessment of economy-wide CO_2 emissions reduction for Lebanon

Subash Dhar[1] & Charles O. P. Marpaung[2]

1. UNEP DTU Partnership, DTU Management Engineering, DTU, UN City, Marmorvej 51, Copenhagen, Denmark
e-mail: sudh@dtu.dk
2. Universitas Kristen Indonesia, Jl. Mayjen Sutoyo No. 2 Cawang, Jakarta 13630, Indonesia

Abstract:

Transport sector is a priority for some countries in Asia within the Technology Needs Assessment project. The technologies that were prioritised, were mainly related to urban transport where besides CO_2 mitigation co-benefits are high in terms of improved air quality, accessibility, safety, health and energy security, Non-motorized transport, mass transit and energy efficient vehicles emerged as the three most preferred technology choices. Transportation technologies also require major changes to infrastructures and therefore CO_2 emission reductions on an economy wide approach are important to understand.

A methodology, based on input-output decomposition analysis, is proposed for analysing economy wide CO_2 emissions reductions for a horizon year. The methodology is applied for the transport sector of Lebanon within the Greater Beirut Area (GBA) where alternative fuels, improvement to cars (private and taxis) and buses for public transport were prioritized by stakeholders. The economy-wide CO_2 emission would reduce by 10.65 % from business case scenario by 2020 for Lebanon if the prioritized technologies are implemented. Fuel mix effect and structural effect reduce CO_2 emission by 2,611 thousand tons, while the final demand effect increases the CO_2 emission by 342 thousand tons.

1. Introduction

Transport sector can play a crucial role for the mitigation of global greenhouse gas emissions (IPCC, 2007). Globally, the share of CO_2 emissions from transport was about 22% in 2008, and the share of energy demand from transport was 19% for the same period (IEA, 2013). The contribution of the developed countries (OECD in 1990) was 3.14 $GtCO_2$ in 2010 as compared to 2.75 $GtCO_2$ for the developing countries and economies in transition (Sims et. al., 2014). Developed countries show variations with a higher share of emissions from North America as compared to Europe and Pacific OECD (Sims et. al., 2014). In the future, an increasing share of energy demand and CO_2 emissions is expected to come from transport sector if the current dynamics continue (IEA, 2013), majority of it from developing countries, where the economic growth and corresponding increase in per capita incomes is leading to an increase in demand for mobility and motorization. 98% of all energy demand for transport comes from fossil fuels and the dependence on fossil fuel is expected to remain high under the business as usual scenario (IEA, 2013). This dependence on fossil fuels, besides having implications for climate change, also presents a big challenge for energy security and trade balance of countries which meet domestic oil needs through imports. Another consequence of fossil fuel use in transport has been the impact on urban air quality and human health (Guttikunda & Mohan, 2014), especially within cities. Cities from developing countries in Asia are low in terms of their per capita CO_2 emissions relative to developed countries (Newman & Kenworthy, 2011) due to a high share of non-motorised modes, bus and rail (Sims et. al., 2014). The future emissions from developing countries would however depend on the infrastructure and city planning pathways (Sims et. al., 2014). Mitigation of CO_2 emissions from transport sector has however been found difficult in both developed countries (Schwanen et. al., 2011) and in developing countries. Mitigation actions taken under the

Clean Development Mechanism (CDM) reveal that the total certified emission reductions of CO_2 for transport sector for the period 2008-2012 accounted for only 2% of the total (Ellis et al., 2007).

A number of developing countries identified transport as a priority sector for their mitigation efforts in the Technology Needs Assessment (TNA) exercises carried under GEF funded TNA project[1]. Mitigation within transport sector can deliver co-benefits e.g., for improved air quality, health (West et al., 2013), energy security (Newman & Kenworthy, 2011; Shukla et al., 2008), accidents, noise and congestion (Creutzig & He, 2009) and therefore transport projects and programs have been taken up by developing countries as a part of their nationally appropriate mitigation actions (NAMAs)[2]. The countries and Technology Executive Committee within the United Nations Framework Convention on Climate Change (UNFCCC) process have been interested to link TNA with NAMAs. Under the NAMA framework however it is important to quantify what an action would contribute in terms of Green House Gas (GHG) mitigation (Lutken et al., 2013). Mitigation within transport sector involves changes in infrastructure and therefore economy wide CO_2 emissions are important to analyse.

In this paper a comparative analysis of country studies from TNA countries in Asia, which prioritised transport sector, is carried out to analyse the criteria used for prioritization and the technology choices. Since the technologies have assumedly benefits for climate a methodology for estimation CO_2 mitigation is provided. The methodology is applied for Lebanon, one of the countries in Asia that prioritised transport, and total change in CO_2 emission in the entire economy due to transport mode improvement in 2020 for the Greater

---

[1] Sectorwise technologies available at <http://tech-action.org/> >

[2] By July 2014 there were three transport NAMA out of a total of 51 NAMA registered < http://namapipeline.org/>

Beirut Area (GBA) are analysed. Furthermore, this study would also analyse the factors which affect the total CO_2 emission changes.

This paper is organized as follows: It starts with a review of technology prioritization within transport sector for the countries in Asia that prioritised transport sector within TNA. Then a methodology for analysing economy wide CO_2 emissions reduction of a technology portfolio for transport sector is presented. In the next section scenarios for GBA are presented, followed by input data and assumptions. The paper ends with a presentation of results, discussion and conclusions.

2. Review of technology prioritization for countries in Asia

Transport as a sector was prioritised by 5 countries out of 12 countries within the TNA project in Asia. Out of these five countries the TNA reports[3] of only four contain a description of scoring and weighting done in the stakeholder consultation process and are the source of data for this section. A wide variety of technologies were considered by the four countries (Supplementary Material) and these are broadly categorized into five mitigation strategies (Table 1).

2.1 Technology Prioritization Methodology

The TNA countries used a stakeholder consultation process to prioritize the technologies within the chosen sectors based on the Multi Criteria Analysis (MCA). MCA has been used widely for prioritization of technologies and policies for climate change (Okinomou et. al., 2010, UNEP, 2011) and MCA technique followed by Department of

[3] Available on TNA project website <http://tech-action.org > Accessed 28 August 2014

Communities and Local Government, UK were used (DCLG, 2009). The stakeholders first identify criteria (See Section 2.2) on which they are to prioritize the technologies. The technology options are next evaluated against each criteria and a matrix is constructed to present in an objective fashion how each technology ranked on different criteria. Quantification is done wherever feasible otherwise standard scales are used to rank the options and these are discussed amongst the stakeholders. This is followed by scoring of the technology options on a scale of 0 to 100 against the various criteria. The most preferable option being given a score of 100 and the least preferred a score of 0. The weightages are finally assigned for the various criteria and in some cases swing weighting is used (DCLG, 2009) however most countries divided a weight of 100 or 1 across criteria. This paper used the weighted scores for various technology options provided by the countries for the analysis. All the scoring from the countries was normalised so that the maximum score that could be obtained by any technology option is 1.

.

2.2 Criteria for measuring sustainability of transport

The discussion around technologies for tackling climate change has been generally carried out within the framework of sustainable development with transfer of technologies (mostly from developed countries) a cornerstone of such efforts (Metz et al. 2000). The contribution to sustainable development has been often been estimated (e.g., within CDM) as benefits for economic, social, and environmental development (Olsen & Fenhann, 2008). In the literature related to indicators for sustainable transport, a similar classification has been followed (Haghshenas et. al., 2012; Tanguay et. al., 2010; Litman, 2007). Mitigation of GHG emissions is generally counted as a part of the environmental benefits. The countries in the TNA project besides considering the impacts of technologies for sustainable development also gave weightage to technology characteristics and in case of two countries this was the most important criteria. GHG mitigation was an important criterion however a higher weightage was given by countries to local environmental issues (Figure 1).

The countries translated the broad themes of economic, social, and environmental development to specific indicators (Table 2). This elaboration was consistent with indicators used for transport sector in literature. A similar elaboration was also done for the criteria related to technology and cost of technology.

2.3. Results of Technology Prioritization

The scores for all the four countries on different technology options (Supplementary Material) were averaged for six different technology strategies i) non-motorised transport (NMT) ii) urban mass transit iii) efficient vehicle technologies iv) planning and management v) rail for intercity and vi) alternative fuels. NMT emerged as the most preferred strategy with an overall score of 0.72. NMT is seen as a preferred option for addressing the environmental and climate concerns however had low scores on technology due to concerns for safety and potential scale of utilization (Figure 2). Urban mass transit was the second most preferred option with an overall score of 0.67 however it scored low on criteria of technology and cost (Figure 2). Urban mass transit involves large investments and this could be a reason for low scores on cost criteria. Urban mass transit is a widely prevalent mode in developed countries however the pessimism of stakeholders (in countries) could be on account of limited experience within the chosen countries of urban mass transit projects. Vehicle and fuel technologies had high scores on cost and technology criteria as the technology options considered were more efficient and commercially proven options like CNG vehicles, more efficient engines, etc. Vehicle and fuel technologies however had low scores on economic and social development since all the four countries are importer of cars and therefore expect limited job creation.

3. Methodology for analysing economy wide GHG mitigation

The quantifications for GHG emissions can be done at a project level, energy system level or at a macroeconomic level. The project level mitigation can be estimated by comparing the project with a project which would assumedly come in the contra factual case (e.g., projects developed under CDM follow this approach). The technology intervention can be also analysed at the energy system level using an energy system model (e.g., refer Bhattacharyya & Timlisima, 2011 for a review of Energy System Models) to analyse the inter-sectoral linkages of the action. Finally, any project intervention has economy wide implications and the contribution of indirect CO_2 emissions from intervention in a sector of the economy are quite significant (Mayer and Flachmann, 2014; Zhu et al., 2012; Bin and Dowlatabadi, 2005).The methodology therefore used in this paper is for analysing economy wide GHG emission reductions.

The economy wide CO_2 emission reductions are analysed using the Input Output (I-O) analysis which offers a practical approach to general equilibrium analysis, allowing for the analysis of direct and indirect repercussions of economic changes of different patterns of final demand and also for estimation of industry specific impacts (Lesser, 1994). The methodology for estimating economy wide CO_2 emissions has been explained with Lebanon as a case study however it can be applied for other cases with suitable modifications. Lebanon prioritized as part of their TNA hybrid electric vehicles and more efficient gasoline engines to rejuvenate the car fleet in Beirut and more efficient diesel and CNG buses to rejuvenate their public transport i.e., bus fleet in Beirut.

The total change in CO_2 emission in the economy due to changes in transport sector is due to three main effects which are not overlapping, i.e., fuel mix effect (FME), structural effect (STE), and final demand effect (FDE). FME generically is due to fuel switching. FME for Lebanon is due to introduction of CNG buses besides diesel. STE generically is due to use of more efficient technologies and which are parameterised through changes in technological coefficients of the I-O table. STE for Lebanon is due to introduction of more fuel efficient gasoline engines and hybrid vehicles. *FDE* is generically due to investment in transport mode improvement which can lead to change in final demand. In case of Lebanon there are two components of the *FDE* (i) the change in final demand due to the change in final demand for goods and services for public transport after bus revitalization (hereafter "*FDE_PT*"), and (ii) the change in final demand due for goods and services for passenger car after fleet renewal (hereafter "*FDE_PC*"). Each individual component under final demand effect (i.e., *FDE_PT* and *FDE_PC*) can be decomposed further into (i) the change in the CO_2 emissions due to the use of fossil fuels directly in the production of goods and services which are used for final demand and (ii) the change in the CO_2 emissions due to the fossil fuels which are expended to produce goods and services which are useful as inputs to produce goods and services for final demand. Thus, *FDE_PT* can be expressed in terms of its direct and indirect effects; these effects are hereafter denoted as "*FDE_PT_D*" and "*FDE_PT_ID*" respectively. Similarly *FDE_PC* can be expressed in terms of its direct- and indirect-effects; these effects are hereafter denoted as "*FDE_PC_D*" and "*FDE_PC_ID*" respectively. Hence the total change (*TC*) in a CO_2 emission is now can be written as:

$$TC = FME + STE + FDE\_PT\_D + FDE\_PT\_ID + FDE\_PC\_D + FDE\_PC\_ID \qquad (1)$$

The symbols used in the decomposition model in this study are defined as follows:

m = types of fuels used by producing sectors,

n = number of producing sectors,

PT = public transport revitalization,

PC = passenger car fleet renewal,

$\boldsymbol{A}_R(t), \boldsymbol{A}_0(t)$ = matrix (n x n) of input-output (i.e., technological coefficients) after and before transport mode improvement in year t respectively,

$\boldsymbol{C}_R(t), \boldsymbol{C}_0(t)$ = matrix (n x m) of direct fuel requirement coefficients (defined as fuel use per unit of total output of a sector) after and before transport mode improvement in year t respectively,

$\boldsymbol{E}$ = column vector (m x 1) of a CO_2 emissions coefficients (defined as CO_2 emissions per unit of fuel used),

$\boldsymbol{I}$ = identity matrix (n x n),

$\boldsymbol{L}_R(t), \boldsymbol{L}_0(t)$ = Leontief matrix (n x n) of input-output after and before transport mode improvement in year t respectively,

$\boldsymbol{X}_R(t), \boldsymbol{X}_0(t)$ = column vector (n x 1) of total output after and before transport mode improvement in year t respectively,

Hereafter, we suppress the time argument in order not to clutter the notations. The derivation of the decomposition model is as follows: First, the difference in total output due to revitalizing transport sector ($\Delta\boldsymbol{X}$) is calculated as follows:

$$\Delta\boldsymbol{X} = \boldsymbol{X}_R - \boldsymbol{X}_0 \qquad (2)$$

Noting that the total output vectors after and before transport mode improvement (i.e., $\boldsymbol{X}_R$ and $\boldsymbol{X}_0$ respectively) can be expressed as $\boldsymbol{X}_R=[\boldsymbol{I}-\boldsymbol{A}_R]^{-1}\boldsymbol{Y}_R$ and $\boldsymbol{X}_0=[\boldsymbol{I}-\boldsymbol{A}_0]^{-1}\boldsymbol{Y}_0$ respectively, Equation (2) can be expressed as:

$$\Delta\boldsymbol{X} = [\boldsymbol{I} - \boldsymbol{A}_R]^{-1}\,\boldsymbol{Y}_R - [\boldsymbol{I} - \boldsymbol{A}_0]^{-1}\,\boldsymbol{Y}_0 \qquad (3)$$

Denoting $\boldsymbol{L}_R \equiv [\boldsymbol{I} - \boldsymbol{A}_T]^{-1}$ and $\boldsymbol{L}_0 \equiv [\boldsymbol{I} - \boldsymbol{A}_0]^{-1}$, Equation (3) can be written as:

$$\Delta\boldsymbol{X} = \boldsymbol{L}_R\,\boldsymbol{Y}_R - \boldsymbol{L}_0\,\boldsymbol{Y}_0 \qquad (4)$$

Equation (4) can be extended to analyse the change in total CO_2 emission *(TC)* after transport mode improvement as compared to that before transport mode improvement by considering the fuel-use coefficients matrices in the cases after and before transport mode improvement (i.e., $\boldsymbol{C}_R$ and $\boldsymbol{C}_0$ respectively) and a matrix of CO_2 emissions coefficients ($\boldsymbol{E}$):

$$TC = \boldsymbol{E}' \boldsymbol{C}_R' \boldsymbol{L}_R \boldsymbol{Y}_R - \boldsymbol{E}' \boldsymbol{C}_0' \boldsymbol{L}_0 \boldsymbol{Y}_0 \quad (5)$$

where $\boldsymbol{C}_R'$ and $\boldsymbol{C}_0'$ represent the transpose of $\boldsymbol{C}_R$ and $\boldsymbol{C}_0$ respectively and $\boldsymbol{E}'$ is the transpose of $\boldsymbol{E}$. The change in total CO_2 emission due to transport mode improvement as stated in Equation (5) is partly due to the final demand effect (*FDE*) and partly due to operating phase effect (*OPE*). The *FDE* and the *OPE* that contribute to the total change in CO_2 emissions can be derived from equation (5) by using polar decompositions or the average of all possible first order decompositions (Dietzenbacher and Los, 1998; Hoekstra and van der Bergh, 2002;) as follows:

$$TC = \boldsymbol{E}' \Delta\boldsymbol{C}' \boldsymbol{L}_R \boldsymbol{Y}_R + \boldsymbol{E}' \boldsymbol{C}_0' \Delta\boldsymbol{L} \boldsymbol{Y}_R + \boldsymbol{E}' \boldsymbol{C}_0' \boldsymbol{L}_0 \Delta\boldsymbol{Y} \quad (6)$$

The first and the second components of the right hand side of Equation (6) is the change in total economy-wide CO_2 emission after transport mode improvement compared to that before transport mode improvement due to fuel mix effect (*FME*) and structural effect (*STE*) respectively while the third component is due to final demand effect (*FDE*). The fuel mix effect and the structural effect are also called as operating phase effect (*OPE*) (Proops et al., 1996). After an algebraic manipulation, the *FDE* component in Equation (6) can also be written as:

$$FDE = \boldsymbol{E}'\boldsymbol{C}_0'\Delta\boldsymbol{Y} + \boldsymbol{E}'\boldsymbol{C}_0'[\boldsymbol{L}_0\text{-}\boldsymbol{I}]\, \Delta\boldsymbol{Y} \quad (7)$$

where, the first and the second components of the right hand side of Equation (7) represent direct- and indirect-effects respectively associated with the change in final demand due to transport mode improvement in the transport sector. Changes in the final demand ($\Delta\boldsymbol{Y}$) comprise of two major categories, i.e., changes in demand for goods and services for (i) revitalization of public transport (ΔY_{PT}) and (ii) passenger car fleet renewal (ΔY_{PC}) or in other words $\Delta Y = \Delta Y_{PT} + \Delta Y_{PC}$. The total change in CO_2 emission due to final demand effect can be decomposed into two parts, i.e., the change associated with the revitalization of public transport (*FDE_PT)* and that related to passenger car fleet renewal (*FDE_PC*); these components can be obtained by substituting ΔY in Equation (7) with (ΔY_{PT} + ΔY_{PC}). Hence, there are four components under the *FDE* that affect the total change in emissions, i.e. (i) the direct effect due to the change of final demand for public transport revitalization (*FDE_PT_D*), (ii) the indirect effect due to the change of final demand for public transport revitalization (*FDE_PT_ID*), (iii) the direct effect due to the change of demand for passenger car fleet renewal (*FDE_PC_D*), and (iv) the indirect effect due to the change of demand for passenger car fleet renewal (*FDE_PC_ID*). Hence, the total change in CO_2 emission in the whole economy due to revitalizing public transport could be disaggregated into six types of effects and each component could be calculated by using the following equations (Equations 8 – 13):

(a) *FME* $= \mathbf{E}'\, \Delta\mathbf{C}(t)'\, \mathbf{L}_R(t)\, \mathbf{Y}_R(t)$ (8)

(b) *STE* $= \mathbf{E}'\, \mathbf{C}_0(t)'\, \Delta\mathbf{L}(t)\, \mathbf{Y}_R(t)$ (9)

(c) *FDE_PT_D* $= \mathbf{E}'\, \mathbf{C}_0(t)'\, \Delta\mathbf{Y}(t)_{PT}$ (10)

(d) *FDE_PT_ID* $= \mathbf{E}'\, \mathbf{C}_0(t)'\, [\mathbf{L}_0(t) - \mathbf{I}]\, \Delta\mathbf{Y}(t)_{PT}$ (11)

(e) *FDE_PC_D* $= \mathbf{E}'\, \mathbf{C}_0(t)'\, \Delta\mathbf{Y}(t)_{PC}$ (12)

(f) *FDE_PC_ID* $= \mathbf{E}'\, \mathbf{C}_0(t)'\, [\mathbf{L}_0(t) - \mathbf{I}]\, \Delta\mathbf{Y}(t)_{PC}$ (13)

4. Scenario Formulation

Lebanon, like other developing countries, faces the dual challenge of protecting the environment while pursuing economic growth in a sustainable manner. CO_2 emissions from Lebanon have been increasing since the last few years and transport sector is the second largest source of CO_2 emission (MoE/URC/GEF, 2012).

The scenarios analyse the impact from improving transport modes within the GBA in Lebanon. GBA has more than 40% of the population of Lebanon. The horizon year is 2020, the end year of short term period of Copenhagen Accord. The analysis is done using two scenarios, i.e., Base Case Scenario 2020 (hereafter "BCS_2020") and Low Carbon Scenario 2020 (hereafter "LCS_2020"). The prioritised technologies from TNA report of Lebanon are taken as a part of the LCS_2020. The technologies prioritised by Lebanon for transport included more efficient buses running on dedicated bus lanes (akin to bus rapid transit system) and more efficient cars (e.g., more efficient gasoline engines, hybrids, etc.) and alternative fuels (e.g., natural gas for vehicles). The technologies were prioritised on the basis of their contribution, besides CO_2 mitigation, to local environment (21% weightage), cost (27% weightage), technology characteristics (30% weightage), social development (3% weightage) and consistency with national policies (3% weightage) (Figure 1).

4.1 Base Case Scenario 2020 (BCS_2020)

Travel Demand

The passenger transport demand in GBA was 1.5 million daily trips in 1994 and is expected to go up to 5 million trips in 2015 i.e.; a CAGR of 5.9% (MoE/URC/GEF, 2012). The CAGR of 5.9% is expected to be the same until 2020 and the condition (i.e., the energy intensity) of the passenger transport system is expected to be the same as is in the previous years. The average trip length was 9.6 km and 50% of trips were less than 5 km in 2011 (MoE/URC/GEF, 2012) and no changes are anticipated.

Public Transport

The public transport caters to 31% of travel demand and relies on taxis, mini buses and buses. In 2007 there were around 8000 buses and 47875 taxis (MoE/URC/GEF, 2012). The buses are both publicly and privately owned. The buses have a low occupancy of around 15.1 for publicly owned buses and around 11.2 for privately owned buses (MoE/URC/GEF, 2012). The occupancy for taxis was around 1.18 excluding the driver. The BCS_2020 assumes that low occupancy rates would continue for public transport till 2020.

Passenger Cars

The private passenger cars cater to 69% of travel demand. In 2007 there were around 1,247,572 passenger cars owned privately (MoE/URC/GEF, 2012). The passenger cars are fairly inefficient with an average efficiency of 11.16 lit gasoline per 100 km as the average age of cars is more than 13 years and 60% of cars have engine displacement more than 2 litres (MoE/URC/GEF, 2012) and the BCS_2020 assumes the same average efficiency for cars till 2020.

4.2 Low Carbon Scenario 2020

The travel demand has been kept unchanged and is same as the BCS_2020.

Public Transport

In the low carbon scenario it is envisaged to run more efficient buses on dedicated bus lanes (akin to a bus rapid transit system) within Beirut. A total of 637 buses are expected to be put into operation with an average occupancy of 30 persons instead of inefficient low occupancy buses (MoE/URC/GEF, 2012). An upfront investment of 400 million USD is also envisaged for vehicles and infrastructures (MoE/URC/GEF, 2012). The additional passenger demand is expected to shift from passenger cars and taxis. These new buses are assumed to have lower fuel consumption by around 25% due to improved drive train technologies. The doubling in occupancy is expected to give a further boost to lowering of CO_2 emissions. In case of taxis it is envisaged that a vehicle scraping program will be started and by 2020 around 12,000 taxis will be replaced by more efficient taxis (MoE/URC/GEF, 2012).

Passenger Cars

Under the vehicle scraping program 10% of passenger cars will be scrapped and replaced by new and more efficient cars (MoE/URC/GEF, 2012). The program will target older cars (cars bought before 2000) which currently constitute 90.4% of vehicle stock. In all around 112,805 passenger cars are assumed to be scrapped by 2020. The new vehicles will be more efficient diesel or gasoline hybrids with an average efficiency of 8.07 lit per 100 km similar to world average for new car fleet in 2005 (FIA/IEA/ITF/UNEP/ICCT, 2011). The changes in car fleet will not lead to any changes to infrastructures. However the vehicles will be more expensive by around USD 4000 per vehicle. The new vehicle's (gasoline hybrids) are expected to have 28.6 % lower CO_2 emissions than the current average (MoE/URC/GEF, 2012).

5. Input Data and Assumptions

The 2009 I-O Table of Lebanon (PCM, 2006) consist of 8 sectors, i.e., (i) agriculture and livestock, (ii) energy & water, (iii) manufacturing, (iv) construction, (v) transportation & communication, (vi) other services, (vii) trade, and (viii) administration. The CO_2 emission by each sector in 2009 is taken from Enerdata[4]. The annual average growth rate of GDP is forecast as 4% per year for 2014 (IMF, 2013) and the same CAGR is continued till 2020.

[4] http://www.enerdata.net/

The technological coefficients of the I-O Table for the year 2020 under the BCS_2020 is the same as that in year 2009, while the technological coefficients for the year 2020 under the LCS_2020 is updated based on transport mode improvement (see Murty et al., 1997; Caloghirou, 1996 and Proops et al, 1996 for updating the technological coefficients).

The values of fuel use (and accordingly the CO_2 emission) per unit output of other producing sectors (except transportation & communication sector) under LCS_2020 are assumed to remain constant at their 2009 levels. The levels of fuel use per unit output of transportation & communication sector under LCS in 2020 correspond to the new technologies that are going to be adopted in the transport sector. The total investment for transport mode improvement in 2020 under LCS is taken from MoE/URC/GEF, 2012.

In the present study, exports are treated as a part of final demand and imports are ignored. A similar approach was followed by Gay & Proops (1993) and Proops et al. (1996) in the case of UK and also consistent with the emission accounting guidelines of the IPCC. If the true picture of Lebanon responsibility for pollution emissions is to be obtained, then the emissions attributable to exports should be subtracted, while the emissions taking place overseas to satisfy import demand should be added on.

6. Results and Discussions

The CO_2 emissions in 2009 were 17.9 Million tCO_2 and in the BCS_2020 these will increase to 21.3 Million tCO_2 in 2020. Transport improvement in Lebanon under the LCS_2020, which consists of revitalization of public transport and passenger car fleet renewal in GBA, would reduce CO_2 emission and all sectors would contribute (Table 3). Among the three effects fuel mix effect (FME) and structural effect (STE) are found to result in reduction of the CO_2 emission by 2,611 thousand tons while the final demand effect (FDE) would increase the CO_2 emission by 342 thousand tons in the country (see Table 3).

The CO_2 emission reduction due to FME are higher than STE, as occupancy rate of buses under LCS_2020 is higher than that of the BCS_2020 which would reduce the energy use and therefore CO_2 emission. Furthermore, fuel switching from diesel to CNG under the LCS_2020 would lower the CO_2 emission. FDE unlike FME and STE would increase the CO_2 emission in the LCS_2020 because more investment is required to improve the transportation mode.

Overall 69.05% of the total CO_2 emission reduction are from transport & communication sector, followed by other services sector at 13.87% and trade sector at 11.97% respectively. The CO_2 emission reductions from the remaining sectors are around 5.11%.

Among the eight sectors the transportation & communication sector contributes 71.9% to mitigation from FME (Table 3). The contribution of other services and trade sector is 22.5% for FME. Similar to FME, Transportation & communication sector shows the highest contribution to STE, i.e., 71.9%. The contribution of other services and trade sector is about 22.5%. Unlike FME and STE, FDE would increase the CO_2 emission from three sectors, i.e., manufacturing, construction, and transportation & communication-sectors. The main contribution to FDE is from transportation & communication-sector, i.e. around 91.1%, followed by construction sector (7.5%) and manufacturing sector (1.4%).

FDE consist of two components, i.e., investment for public transport revitalization, and passenger car fleet renewal. The contribution of public transport revitalization due to FDE is slightly higher than that of the passenger car fleet renewal (Table 4). The results show that the contribution of public transport revitalization to FDE (or FDE_PT) is about 50.6% (or 173 thousand tons), while the contribution of passenger car fleet renewal to FDE (or FDE_PT) is about 49.4% (or 169 thousand tons). The FDE_PT consists of two components, i.e., direct- and indirect-effects. The direct effect of FDE_PT (or FDE_PT_D) is slightly higher than the indirect effect of FDE_PT (or FDE_PT_ID) (Table 4). Similar to FDE_PT, the direct effect of FDE_PC (or FDE_PC_D) is also slightly higher than the indirect effect of FDE_PC (or FDE_PC_ID) (Table 4). Transport and communication sector would contribute the highest to FDE_PT, i.e. 143 thousand tons (or around 82.5%), in which the shares of direct- and indirect-effects are around 65% and 35% respectively. The construction sector and manufacturing sector would contribute to FDE_PT around 14.9% and 2.6% respectively. The shares of direct- and indirect-effects due to the investment in the construction sector for public transport revitalization are 61.3% and 38.7% respectively, while the shares of direct and indirect-effects due to investment in the manufacturing sectors for public transport revitalization are 67.7% and 32.3% respectively. In the case of investment on passenger car fleet renewal, only one sector in the economy is affected, i.e., transportation and communication sector as no changes in infrastructures are considered, in which the shares of direct- and indirect-effects are 64.8% and 37.2% respectively.

7. Conclusions

Transport sector emerged as a priority for some countries in Asia. The technologies prioritized were predominantly for urban transport where the co-benefits are high in terms of improved air quality, mobility, accessibility, safety, health, and energy security. Non-motorized transport emerged as the most preferred option followed by mass transit and efficiency improvement in vehicles. It was quite clear that despite high co-benefits for economic, social and environmental development the options face serious barriers. In case of NMT the perception of safety for users and the limited role it can play for longer trips are the two key barriers. Urban mass transit was the second preferred option however was perceived costly and not well proven in developing countries. Improvements in vehicle technology were not perceived to be contributing sufficiently for economic and social development. Therefore additional support from climate side for urban mass transit and vehicle technology can definitely help in mainstreaming these options.

The case study for Lebanon demonstrated that technologies prioritized for transport sector contribute economy wide towards mitigation of CO_2 emissions. The approach can be applied for other countries, albeit with suitable modifications, which are prioritizing technologies and intending to upscale them into NAMAs.

The Lebanon case study shows that the overall CO_2 emission would decrease by 10.65 % from BCS if the technologies prioritised within transport sector are adopted in 2020. There are three main effects which affect the total CO_2 emission changes, i.e., fuel mix effect, structural effect and final demand effect. The fuel mix effect and structural effect lead to a total CO_2 emission reduction of 2,611 thousand tons while the final demand effect would increase the CO_2 emissions by 342 thousand tons. The CO_2 emission reduction from fuel mix effect and structural effect can be attributed to changes in fuel mix (e.g., from diesel to CNG for buses), improvement in vehicle occupancy and improvement in fuel efficiency. Changes in fuel would however entail changes in infrastructures for fuelling which are reflected in increased emissions under the fuel demand effect. Improved occupancy for buses would also need changed management practices that improve reliability of public transport. The increase in CO_2 emissions from investment on public transport revitalization are almost equivalent to passenger car fleet renewal however emissions from production of cars are not counted as Lebanon imports cars. On a life cycle basis therefore increase in emissions from passenger car fleet renewal would be higher. Therefore improving public transport might be a more effective strategy for reducing CO_2 emissions than improving efficiency of private transport.

References

Bhattacharyya, S.C. and. Timilsina, G.R: (2010) "A review of energy system models", *International Journal of Energy Sector Management* **4**(4), 494 – 518

Bin, S. and Dowlatabadi, H., (2005). Consumer lifestyle approach to US energy use and the related CO2 emissions. *Energy Policy* **33**, 197-208.

DCLG (2009). Multi-criteria analysis: a manual. Department for Communities and Local Government, UK Government,

Dietzenbacher, E., Los, B. (1998) 'Structural decomposition techniques: sense and sensitivity', *Economic Systems Research*, **10**,. 307-323.

Caloghirou, Y. D., Mourelatos, A. G. and Roboli, A. (1996). Macroeconomic impacts of natural gas introduction in Greece. *Energy* **12**(10), 899-909.

Creutzig, F., and D. He. 2009. Climate change mitigation and co-benefits of feasible transport demand policies in Beijing. *Transportation Research Part D: Transport and Environment*.**14**,120-131.

Ellis, J., H. Winkler, J. Corfee-Morlot, and F. d. r. Gagnon-Lebrun. 2007. CDM: Taking stock and looking forward. *Energy Policy*.**35**,15-28.

FIA/IEA/ITF/UNEP/ICCT. (2011). Global Fuel Economy Initiative - Plan of Action 2012-2015. in. International Energy Agency , Available at <http://www.iea.org/media/files/GlobalFuelEconomyInitiativePlanofAction20122015.pdf>.

Gay, P. W. and Proops, J. L. (1993). Carbon-dioxide production by the UK economy: an input-output analysis. *Applied Energy* **44**, 113-130.

Guttikunda S.K. and Mohan D. (2014) Re-fueling road transport for better air quality in India. *Energy Policy* **68**:556-561

Haghshenas H. and Vaziri M (2012) Urban sustainable transportation indicators for global comparison. *Ecological Indicators* **15**:115-121

Hoekstra, R., van der Bergh, J.C.J.M. (2002) 'Structural decomposition analysis of physical flows in the economy', *Environmental and Resource Economics*, **23**, 357–378.

Intergovernmental Panel on Climate Change (IPCC) (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IEA. (2013). World Energy Outlook 2013. OECD/IEA, Paris.

IMF. (2013). World Economic Outlook: April 2013. in. International Monetary Fund Available at <http://www.imf.org/external/pubs/ft/weo/2013/01/pdf/text.pdf>.

Lesser, J. A. (1994). Estimating the economic impacts of geothermal resource development. *Geothermic* 23(1), 43-59.

Litman, T. (2007). Developing indicators for comprehensive and sustainable transport planning. *Transportation Research Record*: 10-15.

Lutken, S. E., B. Dransfeld, and S. Wehner. (2013). Guidance for NAMA Design: Building on Country Experiences. UNFCCC, UNEP & URC,

Mayer H. and Flachmann, C. (2014) Environmental-Economic Accounting- Direct and Indirect CO_2 Emissions in Germany, 2000-2010. Statistisches Bundesamt, Wiesbaden, Germany.

Metz, B., O. R. Davidson, J. W. Martens, S. N. van Rooijen, and L. van Wie McGrory, editors. (2000). Methodological and Technological Issues in Technology Transfer: A Special Report of the Intergovernmental Panel on Climate Change. Cambridge Universities Press, Cambridge, United Kingdom.

MoE/URC/GEF. (2012). Lebanon : Technology Needs Assessment Report for Climate Change. Ministry of Environment (MoE), Beirut, Lebanon

MoE (2011) Lebanon's Second National Communication to UNFCCC, Ministry of Environment (MoE), Beirut, Lebanon

Murty, N. S., Panda, M. and Parikh, J. (1997). Economic development poverty reduction and carbon emissions in India. *Energy Economics* **19**, 327-354.

Newman, P., and J. Kenworthy. (2011). Evaluating the Transport Sector's Contribution to Greenhouse Gas Emissions and Energy Consumption. in R. Salter, S. Dhar, and P. Newman, editors. *Technologies for Climate Change Mitigation: Transport Sector*, UNEP Risoe Centre

Oikonomou, V., Flamos, A. and S. Grafakos, (2010). Is blending of energy and climate policy instruments always desirable? *Energy Policy*, 38 (8), 4186-4195.

Intergovernmental Panel on Climate Change (IPCC) (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK and New York, NY, USA.

IEA. (2013). World Energy Outlook 2013. OECD/IEA, Paris.

IMF. (2013). World Economic Outlook: April 2013. in. International Monetary Fund Available at <http://www.imf.org/external/pubs/ft/weo/2013/01/pdf/text.pdf>.

Lesser, J. A. (1994). Estimating the economic impacts of geothermal resource development. *Geothermic* 23(1), 43-59.

Litman, T. (2007). Developing indicators for comprehensive and sustainable transport planning. *Transportation Research Record*: 10-15.

Lutken, S. E., B. Dransfeld, and S. Wehner. (2013). Guidance for NAMA Design: Building on Country Experiences. UNFCCC, UNEP & URC,

Mayer H. and Flachmann, C. (2014) Environmental-Economic Accounting- Direct and Indirect CO_2 Emissions in Germany, 2000-2010. Statistisches Bundesamt, Wiesbaden, Germany.

Metz, B., O. R. Davidson, J. W. Martens, S. N. van Rooijen, and L. van Wie McGrory, editors. (2000). Methodological and Technological Issues in Technology Transfer: A Special Report of the Intergovernmental Panel on Climate Change. Cambridge Universities Press, Cambridge, United Kingdom.

MoE/URC/GEF. (2012). Lebanon : Technology Needs Assessment Report for Climate Change. Ministry of Environment (MoE), Beirut, Lebanon

MoE (2011) Lebanon's Second National Communication to UNFCCC, Ministry of Environment (MoE), Beirut, Lebanon

Murty, N. S., Panda, M. and Parikh, J. (1997). Economic development poverty reduction and carbon emissions in India. *Energy Economics* **19**, 327-354.

Newman, P., and J. Kenworthy. (2011). Evaluating the Transport Sector’s Contribution to Greenhouse Gas Emissions and Energy Consumption. in R. Salter, S. Dhar, and P. Newman, editors. *Technologies for Climate Change Mitigation: Transport Sector*, UNEP Risoe Centre

Oikonomou, V., Flamos, A. and S. Grafakos, (2010). Is blending of energy and climate policy instruments always desirable? *Energy Policy*, 38 (8), 4186-4195.

Olsen, K. H., and J. Fenhann. (2008). Sustainable development benefits of clean development mechanism projects: A new methodology for sustainability assessment based on text analysis of the project design documents submitted for validation. *Energy Policy* **36,** 2819-2830.

Presidency of the Council of Ministers (PCM), (2006). Economic Accounts of Lebanon, 2003.

Proops, J. L. R., Gay,P. W., Speek, S., Schroder, T. (1996) 'The life time pollution implications of various types of electricity generation: an input-output analysis', *Energy Policy*, **24**,. 229-237.

Schwanen, T., D. Banister, and J. Anable. 2011. Scientific research about climate change mitigation in transport: A critical review. *Transportation Research Part A: Policy and Practice*, . **45**, . 993-1006.

Shukla, P. R., Dhar, S. Mahapatra, D. (2008). Low Carbon Society Scenarios for India. *Climate Policy*. **8**, S156-S176.

Sims R, Schaeffer R, Creutzig F, Nunez XC, D'Agosto M, Dimitriu D, Meza MJF, Fulton L, Kobayashi S, Lah O, McKinnon A, Newman P, Ouyang M, Schauer JJ, Sperling D, Tiwari G (2014) Chapter 8: Transport. In: Mitigation. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Tanguay GA, Rajaonson J, Lefebvre J-Fo and Lanoie, P. (2010) Measuring the sustainability of cities: An analysis of the use of local indicators. *Ecological Indicators* **10**:407-418

UNEP, (2011) A Practical Framework for Planning Pro-Development Climate Policy. United Nations Environment Programme <http://www.unep.org/pdf/Planning_Pro-Dev.pdf> Accessed on 12 Nov 2013.

West, J. J., Smith, S. J., Silva, R. A., Naik, V., Zhang, Y., Adelman, Z., Fry, M. M. , Anenberg, S. , Horowitz, L. W. and Lamarque, J.-F.. (2013). Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health, *Nature Climate Change* **3**:885-889.

Zhu, Q., Peng, X., Wu, K. (2012). Calculation and decomposition of indirect carbon emissions from residential consumption in China based on the input-output model. *Energy Policy* **48**, 618-626

Table 1. An overview of technologies prioritised in the transport sector in TNA project by countries in Asia

Mitigation Strategies	Technologies Prioritised			
	Bhutan	**Cambodia**	**Lebanon**	**Sri Lanka**
Non-motorized Transport	1			1
Urban Mass Transit	1	1		
Planning & Management	1			1
Rail for intercity				1
Efficient Vehicle Technologies		1	3	
Grand Total	**3**	**2**	**3**	**3**

Table 2. Criteria considered by countries for transport sector

Criteria	Indicators
Economic Development	• Traffic congestion / time efficiency • Energy security • Job creation & livelihoods
Social Development	• Equity: access to transport, impact on vulnerable groups • Food security • Cultural acceptance • Health benefits • Sustainable society
Environmental Development	• Air, water and soil pollution • Biodiversity • Reduction of hazardous waste • Noise reduction
Technology	• Energy efficiency (Fuel savings) and emissions • Safety of technology • Reliability of technology • Maturity • Potential scale of utilization
GHG Mitigation	• CO_2 Emissions
Cost of Technology	• Low infrastructure costs • Capital cost of technology • O & M costs
Others	• Relevance to national plans

Table 3. Factors which affect the reduction of CO_2 emission on sectoral basis (in thousand tCO_2)

Sectors	FME	STE	FDE	Total
Agriculture & livestock	-2.15	-0.71	0	-2.86
Energy & water	-1.53	-0.50	0	-2.03
Manufacturing	-32.68	-10.74	4.70	-38.72
Construction	-26.12	-8.58	25.71	-8.99
Transportation & communication	-1413.36	-464.51	311.16	-1566.71
Other services	-236.85	-77.84	0	-314.69
Trade	-204.36	-67.17	0	-271.53
Administration	-47.80	-15.71	0	-63.51
Total	-1964.85	-645.76	341.57	-2269.04

Table 4. CO_2 emission contribution of direct- and indirect-effects of final demand effect due to public transport revitalization and passenger car fleet renewal (in thousand tCO_2)

Sectors	Public Transport		Passenger Car	
	FDE_PT_D	FDE_PT_ID	FDE_PC_D	FDE_PC_ID
Agriculture & livestock	0	0	0	0
Energy & water	0	0	0	0
Manufacturing	2.88	1.82	0	0
Construction	17.40	8.31	0	0
Transportation & communication	92.71	49.95	109.50	59.00
Other services	0	0	0	0
Trade	0	0	0	0
Administration	0	0	0	0
Total	**112.99**	**60.08**	**109.50**	**59.00**

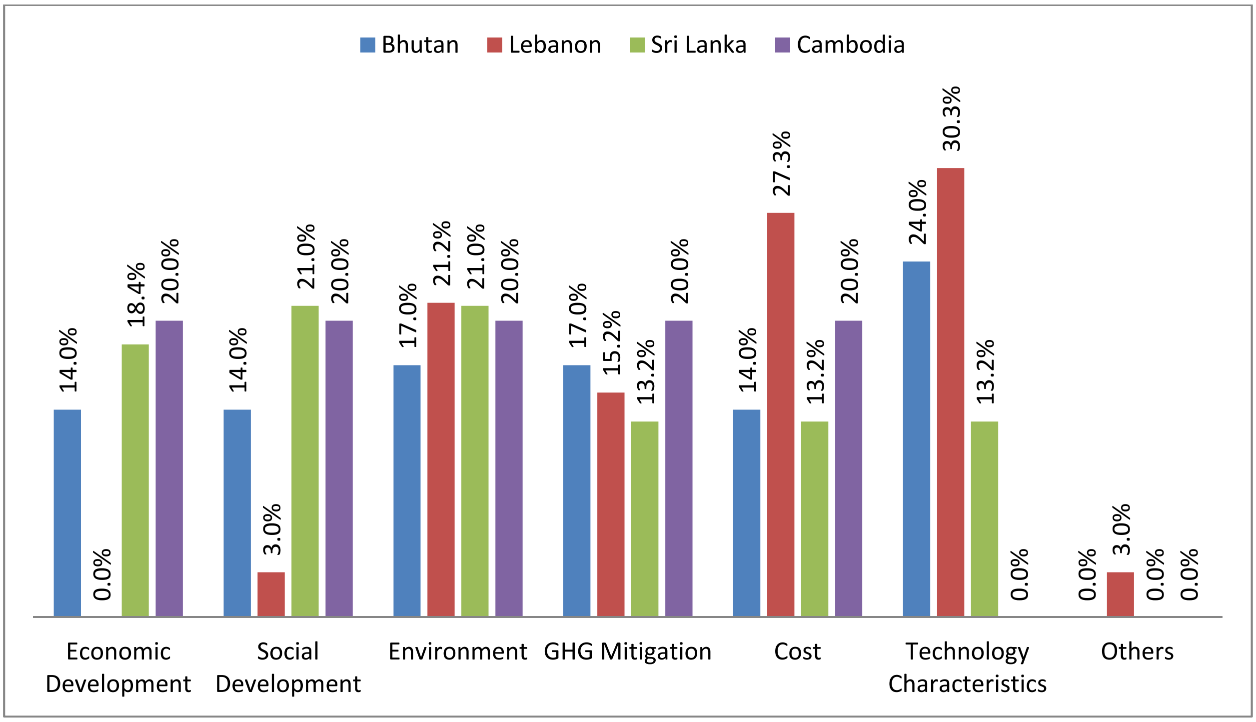

Figure 1. Weightage given by countries to different criteria

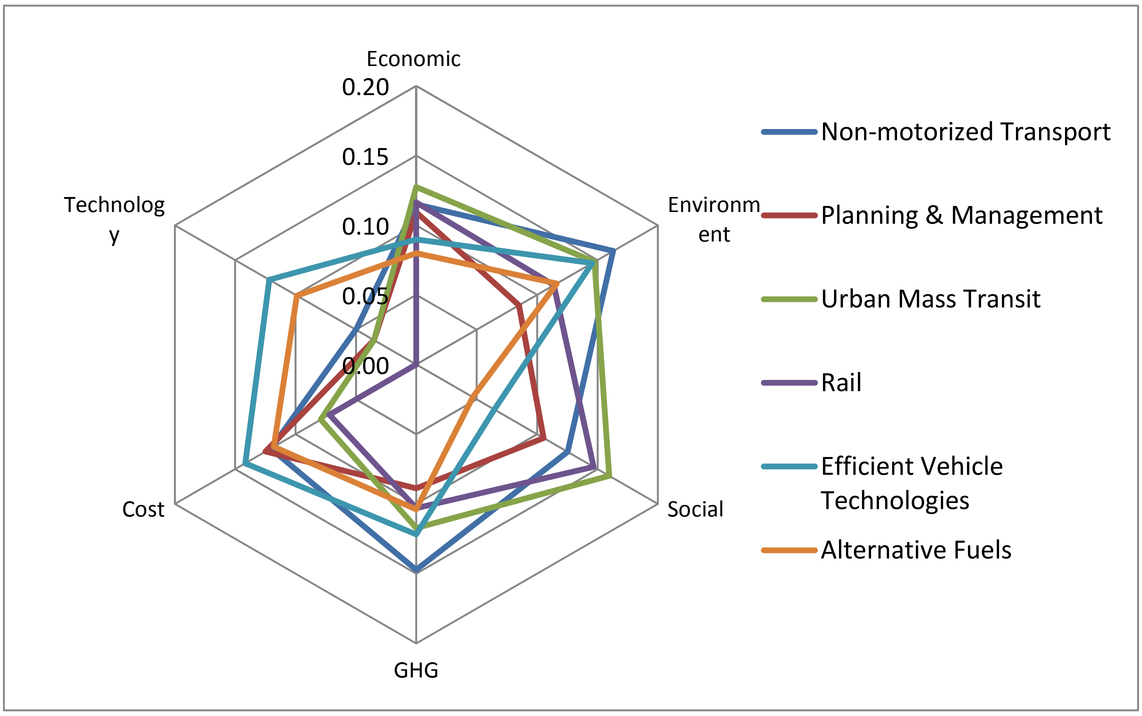

Figure 2. Average scores for different technology strategies