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GLOBAL CLIMATE CHANGE MITIGATION: WHAT IS THE ROLE OF DEMAND REDUCTION?

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Abstract

There are different options to reduce CO_2 emissions: efficiency improvement, structural changes to low carbon or carbon-free technologies, sequestration and demand reduction. While the decarbonisation of secondary energy carriers and technological changes have an important role in climate change mitigation, this paper addresses the role of demand reduction. For this analysis, the elastic demand version of the TIAM-UCL global energy system model is used under different long-term low carbon energy scenarios through to 2100 at low, medium and high values for demand elasticity. The role of demand reduction is examined by means of decomposition analysis at regional and global level. The results of the emission decomposition indicate that a reduction in the demand for energy services can play a limited role, contributing around 5% to global emission reduction in the 21st century. A look at the sectoral level reveals that demand reduction is very different from sector to sector with demand reduction contributing around 16% in the transport sector and about 2% in the residential sector at a global level. Analysis also finds that demand reduction can significantly affect the regional emission mix.

Introduction

Human beings demand energy in order to meet services such as heating, cooling, lighting, cooking, moving, etc., via end-use devices, which consume final energy. In order to provide energy service demands, conversion technologies (for example power plants) are used to transform primary energy (for example coal) to final energy (for example electricity) and infrastructure to transport energy. Most of the primary energy sources are fossil fuels (hydrocarbons). Technologies are involved all the way from upstream to end-use sectors emitting a large amount of CO_2 and other gases by burning fossil fuels.

As a response to the twin challenges of climate change mitigation and energy security there are several research and modelling exercises carried out mostly discussing options like shifting to low carbon fuels, renewable energy and improving efficiency of conversion and end-use technology. As human beings demand energy services, reducing energy services demand will ceteris paribus result in lower energy consumption and consequently reduce CO_2 emissions all the way from upstream to conversion to end-use devices. Demand reacts to price changes: an increased supply price will results in a decreased demand or vice versa. This paper analyses the role of demand reduction in meeting global CO_2 mitigation target by decomposing the results of the TIAM (TIMES Integrated Assessment Model)-UCL global energy system model. Logarithmic mean Divisia index (LMDI) decomposition technique has been used.

There are different studies that used TIAM to analyse global energy and emissions scenarios (Syri et al. 2008; Loulou et al. 2009; Ekholm et al. 2010, Lechon et al. 2005, Vaillancourt et al.2008). Though some studies used the elastic demand version of TIAM, they focussed mainly on methodological issues, technological contributions, sectoral emissions, sequestration, etc. These studies did not explicitly analyse the role of demand reduction.

This paper is divided into five sections: following the introduction, Section 2 discusses the TIAM-UCL model and the decomposition technique used in this paper; Section 3 defines the scenarios for analysis; Section 4 discusses the role and implications of demand reduction and Section 5 concludes the paper.

Methodology

TIAM-UCL

The new 16-region TIAM-UCL model has been developed under the UK Energy Research Centre (UKERC) Phase II project by breaking out the United Kingdom (UK) from the Western Europe Region in the 15 Region ETSAP-TIAM model[1]. TIAM, an acronym for TIMES integrated assessment model, is a cost optimisation partial equilibrium model that minimises total discounted energy system cost in the standard version and maximises total societal welfare in the elastic demand version.

Under fixed energy services demands in the standard TIAM-UCL global model, CO_2 reduction is achieved by shifting to efficient technologies, alternative fuels (low/zero carbon fuels) and sequestration. In the elastic demand version of the partial equilibrium model, energy services demands respond to price changes (Loulou and Labriet, 2007). In the elastic demand version, demand functions are defined which determine how each energy service demand varies as a function of the market price of that energy service. The demand function has the following functional form:

$ES/ES_0 = (p/p_0)\ E$

Where:

ES is a demand for an energy service in the policy scenario; ES_0 is the demand in the reference case;

p is the price of each energy service demand in the policy scenario; p_0 is the marginal price of each energy service demand in the reference case;

E is the (negative) own-price elasticity of the demand.

A combination of the change in prices (p/p_0) and the elasticity parameter (E) determines the energy service demand changes. Note that changes in energy service demand also depend on the availability and costs of technological conservation, efficiency and fuel switching options as they influence the energy service price

The reference prices are generated in a non-mitigation scenario where fixed energy services demands are met in a least cost manner. In addition to shifting to efficient technologies, low carbon fuels and sequestration, demand reduction also plays a role in reducing CO_2 emissions in the elastic demand version of the TIAM-UCL model. Demand reduction depends on the price elasticity of demand and incremental costs of alternative options available to meet the energy services demand. The elasticities used in the TIAM-UCL model are long-run elasticities (presented in Table 1) and are the same as used in the ETSAP-TIAM model. It is important to note the aggregate nature and sparse empirical basis for the price elasticities of energy service demands, so that sensitivity analysis around the elasticities is of significant importance.

[1] Further reading on ETSAP-TIAM model is available in Loulou and Labriet, 2007 and Loulou et al., 2009

Table 1: Price elasticity of demand used in TIAM-UCL (constant during 2010-2100)*

Energy services demand	Region 1		Region 2	
	UP	LO	UP	LO
Commercial- space cooling	-0.40	-0.25	-0.15	-0.05
Commercial- cooking	-0.10	-0.05	-0.05	0.00
Commercial- space heating	-0.20	-0.10	-0.10	0.00
Commercial- hot water heating	-0.25	-0.15	-0.10	0.00
Commercial- lighting	-0.25	-0.15	-0.15	0.00
Commercial- electric equipment	-0.40	-0.20	-0.05	0.00
Commercial- refrigerators and freezers	-0.20	-0.15	0.00	0.00
Industry- Chemicals	-0.10	-0.10	-0.10	-0.10
Industry- iron and steel	-0.10	-0.10	-0.10	-0.10
Industry- pulp and paper	-0.10	-0.10	-0.10	-0.10
Industry- non-ferrous metals	-0.10	-0.10	-0.10	-0.10
Industry- non metal minerals	-0.10	-0.10	-0.10	-0.10
Industry- other industries	-0.10	-0.10	-0.10	-0.10
Residential- space cooling	-0.25	-0.10	-0.15	-0.05
Residential- cloth dryers	-0.10	-0.05	-0.05	0.00
Residential- cloth washers	-0.10	-0.05	-0.05	0.00
Residential- dish washers	-0.10	-0.05	-0.05	-0.03
Residential- miscellaneous electric energy	-0.40	-0.30	-0.20	-0.05
Residential- space heating	-0.15	-0.05	-0.05	0.00
Residential- hot water heating	-0.20	-0.15	-0.05	0.00
Residential- cooking	0.00	0.00	0.00	0.00
Residential- lighting	-0.20	-0.10	-0.10	0.00
Residential- refrigerators and freezers	-0.40	-0.30	-0.05	-0.03
Transport- domestic aviation	-0.20	-0.20	-0.20	-0.20
Transport- international aviation	-0.30	-0.30	-0.30	-0.20
Transport- buses	-0.15	-0.15	-0.15	-0.05
Transport- commercial trucks	-0.10	-0.10	-0.15	-0.05
Transport- three wheelers	-0.10	-0.10	-0.05	-0.05
Transport- heavy trucks	-0.10	-0.10	-0.15	-0.05
Transport- light trucks	-0.60	-0.40	-0.15	-0.05
Transport- medium trucks	-0.10	-0.10	-0.15	-0.05
Transport- autos (cars)	-0.60	-0.40	-0.15	-0.05
Transport- two wheelers	-0.10	-0.10	-0.05	-0.05
Transport- freight rail	-0.10	-0.10	-0.15	-0.05
Transport- passenger rail	-0.10	-0.10	-0.15	-0.10
Transport- domestic navigation	-0.10	-0.10	-0.20	-0.15
Transport- international navigation	-0.15	-0.15	-0.20	-0.15

Source: ETSAP-TIAM model

* Region 1: Africa, China, Central and South America, Eastern Europe, Former Soviet Union, India, Middle-East, Mexico and Other Developing Asia; Region2: Australia, Canada, Japan, United States of America, Western Europe and United Kingdom.

Decomposition technique

This paper explicitly investigates the role of demand reduction by decomposing the CO_2 reduction resulting from the imposed constraints into its drivers. Index decomposition analysis represents in this context an appropriate tool to set forth the contribution of driving factors behind the change of an aggregate variable. The focus here is on the contribution of demand reduction towards CO_2 mitigation. Therefore, the decomposition formula is kept very simple in the following way:

$$CO_2 = Demand * \frac{CO_2}{Demand} \tag{1}$$

The first factor on the right hand side is the energy service demand, while the second can be interpreted as the CO_2 intensity of demand. This last term is an aggregated variable that incorporates structural effects, efficiency changes and fuel switches. Since this paper discusses only the influence of demand changes in CO_2 reduction, the latter factor is not further detailed. However, it should be noted that the contribution of the demand factor will remain the same independent of what other factors are included in the decomposition formula (see Sun et al. 1998)

As we are not interested in the absolute level of CO_2 emissions, but rather in the changes of CO_2 emissions between the reference and the mitigation scenario, a decomposition of the change has the following form:

$$\Delta CO_2 = \Delta Demand + \Delta \frac{CO_2}{Demand} + residual \tag{2}$$

In this paper, the additive variant of the logarithmic mean Divisia index (LMDI) (Ang et al. 1998) is used in order to eliminate the residual. Decomposition analysis is a series expansion, which is truncated at first order and therefore possesses a residual. Nevertheless, the redistribution of this residual in the case of the LMDI simplifies the interpretation for decision makers. The LMDI method was chosen as it is judged easy to calculate and does not differ significantly from other methods that do not leave a residual. Thus, the exact decomposition formula looks as follows:

$$\Delta CO_2 = \frac{CO_2^T - CO_2^0}{ln\, CO_2^T - \ln CO_2^0} * ln\left(\frac{Demand^T}{Demand^0}\right) + \frac{CO_2^T - CO_2^0}{ln\, CO_2^T - \ln CO_2^0} * ln\left(\frac{\frac{CO_2^T}{Demand^T}}{\frac{CO_2^0}{Demand^0}}\right) \tag{3}$$

Scenarios

There are five different scenarios defined for this analysis. One is without climate change policies and all other four scenarios are with climate change mitigation policy (constraining regional annual emissions). Three of the low carbon scenarios are run with the elastic demand version of the TIAM-UCL model. In this context, the reference scenario is used as a benchmark for the low-carbon scenarios. Since the elasticities for energy service demands in the different end-use sectors are not well understood, we developed three scenarios with varied assumptions on the demand elasticity.

The scenarios are defined as follows:

1. Reference Scenario (REF): no climate change policy is applied
2. Low Carbon Scenario (LC-STD): Constraining individual regions to reduce global CO_2 emissions to meet 450 ppm CO_2 concentrations. In 2050 and post 2050, -80% target for Annex I countries, -30% target for China and India, and +30% target for all other regions compared to the 2005 CO_2 emission levels. Standard version of the TIAM-UCL is used.
3. Low Carbon Scenario-Elastic Demand (LC-MED): elastic demand version of the TIAM-UCL is used. Otherwise same as the LC-STD.
4. Low Carbon Scenario-Higher Elasticity (LC-HED): price elasticity of demand is 50% higher than that in LCS-ED.
5. Low Carbon Scenario-Lowe elasticity (LC-LED): price elasticity of demand is 50% lower than that in LCS-ED.

Results

CO_2 emissions in REF Scenario

Regional CO_2 emissions are presented in Figure **1** in the REF scenario during 2005-2100. Global energy related CO_2 emissions increases fourfold during this century in the absence of climate change mitigation policies. The current biggest contributor China will increase its contribution to global CO_2 emissions from 18% in 2005 to 29% in 2100 while the share of the USA decreases from 22% to 11% during the same period. Overall, developing countries emissions increase more rapidly than developed countries, which currently contribute over half of the emissions, and are responsible for more than two third of the global emissions in 2100. The reason for this is the assumed high growth rate for drivers (GDP and sectoral outputs) that affect energy service demands and a shift towards energy intensive industry in developing countries leading to a rapid increase in energy demand and consequently CO_2 emissions.

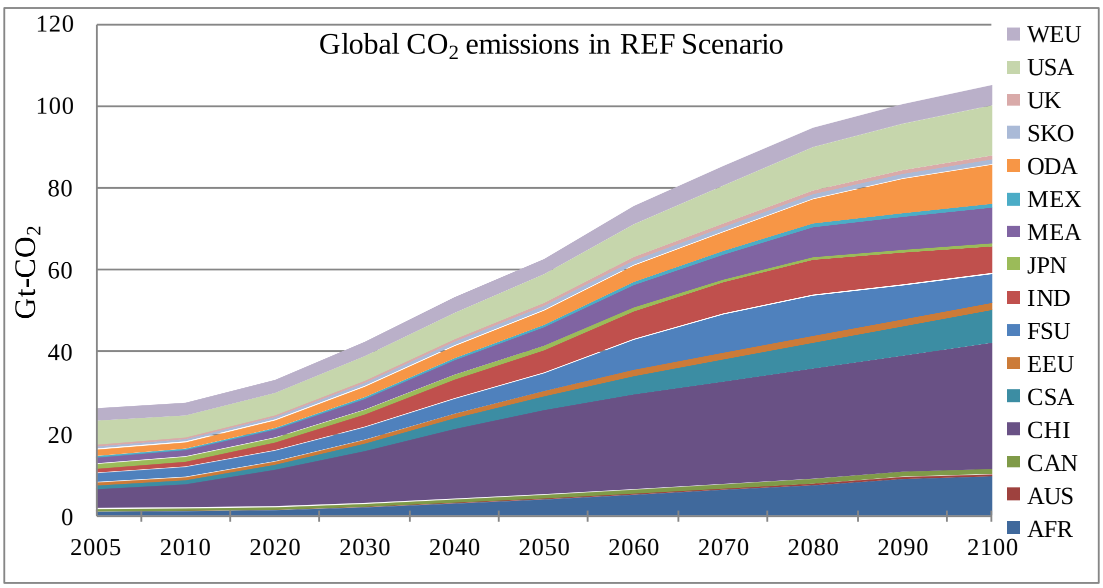

Figure 1: Regional CO_2 emissions in the REF Scenario

Demand reduction

The demand reduction level is influenced by the demand function that is constructed based on the price elasticity and reference prices implicitly constructed in the REF scenario. The level of demand reduction then depends on both the price elasticity of demand and the prices of alternative technologies and fuels available to meet the particular energy service demand. For a particular energy service demand, the demand reduction level will be high if alternative technologies possess a relatively high incremental cost (or vice versa).

Demand reduction under different scenarios (high, medium and low values for elasticity) are presented in Figure **2**, Figure **3**, Figure **4** and Figure **5** for industry, residential, non-road transport (aviation and shipping), and road transport sectors respectively. Results show that demand reduction is highly sensitive to the respective elasticity in all sectors. Industry sector demand reduction goes up to 4.7% in the low elasticity scenario (LC-LED) and up to 12% in the high elasticity scenario (LC-HEL). Since the growth rate of energy intensive industries are high in developing countries like China and India, the industry sector demand reductions are relatively high for those countries (Figure **2**). Elasticity plays a key role in the residential sector demand reduction. Higher demand elasticity for the residential sector energy services demand in developing countries results in a higher demand reduction from the developing countries.

Non-road transport demand reduction goes up to 26%, which is relatively high as compared to that in road transport (maximum 6%) in 2100 in the high elasticity scenario (LC-HED). This is due to the fact that the latter (for example car) has low carbon alternative options at lower incremental cost while the former (for example air craft) has very limited low alternative options with very high incremental cost. Demand reduction for road transport is relatively high for developing while the demand reduction for non-road transport such as aviation and shipping is relatively high for developed countries. This is due to the high elasticity values for the respective regions.

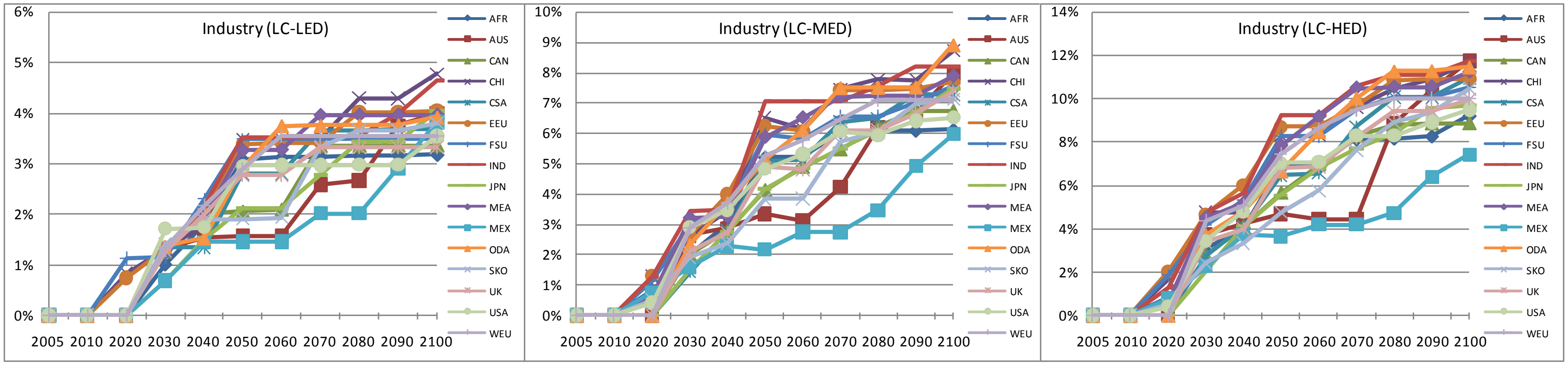

Figure 2: Demand reduction level in industry sector under different scenarios

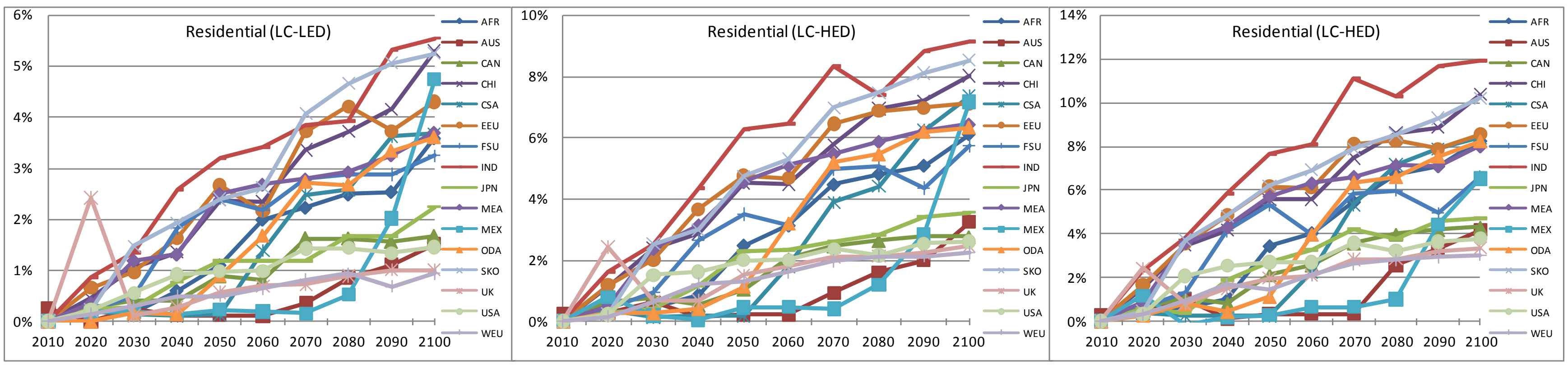

Figure 3: Demand reduction level in residential sector under different scenarios

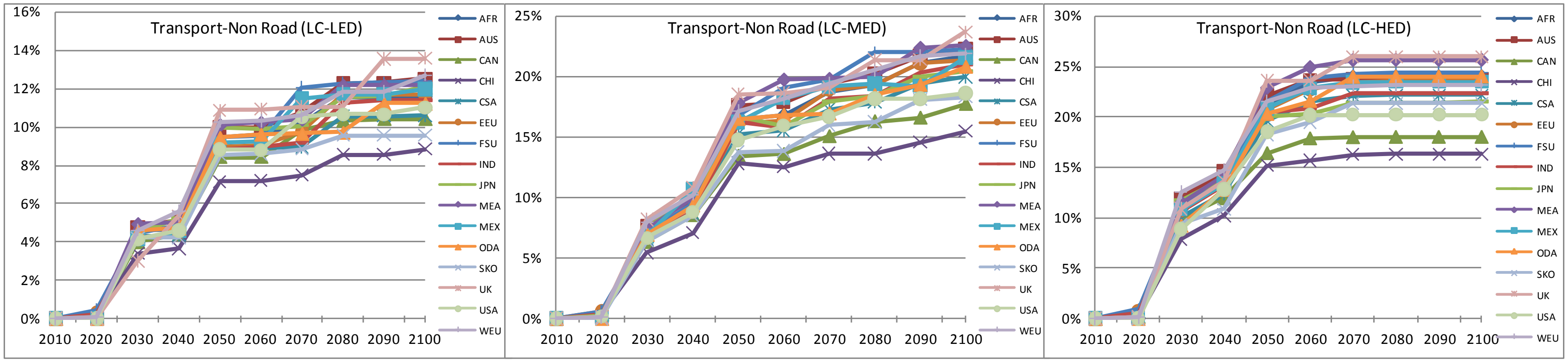

Figure 4: Demand reduction level in non-road transport sector under different scenarios

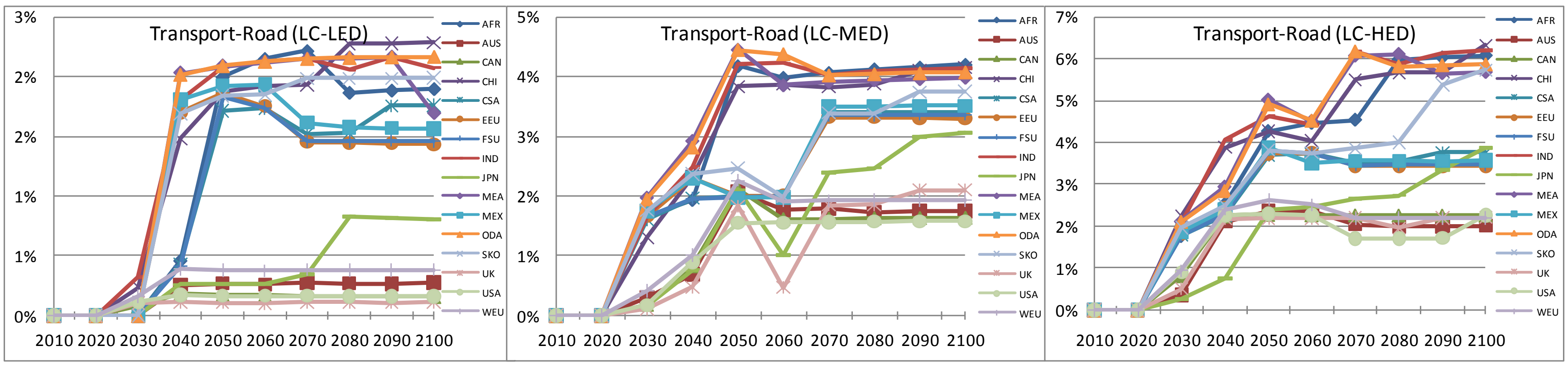

Figure 5: Demand reduction level in road transport sector under different scenarios

Role of demand reduction in climate change mitigation

<u>Overall contribution</u>

The role of demand reduction in global CO_2 mitigation is analysed under a cap-and-trade policy using the elastic demand version of TIAM-UCL. The low carbon scenarios are analysed under the assumption that cap-and-trade policy is in effect—any country can buy emissions from other countries in order to meet their target.

Results of the decomposition analysis indicate that the contribution of demand reduction to overall CO_2 reduction, when comparing the elastic demand low carbon scenarios with the -REF scenario, is in all scenarios around 5% (±2%) (Figure **6**). While the contribution of demand reduction tends to be highest in early periods (2020-230) with up to 9% due to the lack of cost-efficient low-carbon technologies, the demand share decreases towards the end of the 21st century. This does not mean that the demand reduction (change in energy service demand as compared to the REF scenario) decreases towards the end of the century. In contrast, the demand reduction increases over the period (Figure 2, Figure 3, Figure 4 and Figure 5). The contribution of technological options to meet the increasing CO_2 reduction targets increases over the period due to greater availability of cheaper low/zero carbon technologies. Consequently, the CO_2 emission reduction from structural changes and efficiency gains outweigh the demand contribution in the later part of the 21st century and decrease its share of the total abated amount.

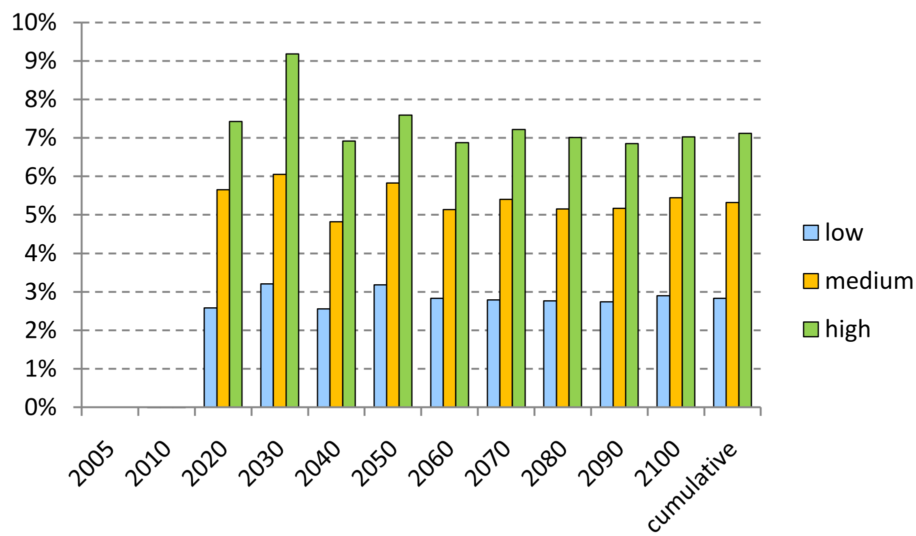

Figure 6: Contribution of global demand reduction to overall emission reduction

The variation of the demand elasticity reveals that the contribution of demand reduction towards a mitigation of CO_2 emissions is highly sensitive to the assumed elasticity level. Consequently, overall demand contribution varies between 3% and 7%. Since demand contribution in the medium case is only 5%, even a high demand elasticity does not drastically increase the contribution of demand reduction.

Regional contribution

In order to gain more insights into the global structure of the contribution of demand reduction to emission mitigation, regional results are depicted in Figure 7 (USA and Western Europe) and Figure 8 (India and China). Common features are that there is virtually no contribution from demand reduction before 2020 due to the fact that the emission trajectories between the reference and the mitigation scenarios do only start to diverge from 2020 onwards. Furthermore, demand contribution tends to be highest in the early 21st century (2020-2030), while this contribution is diminished with time.

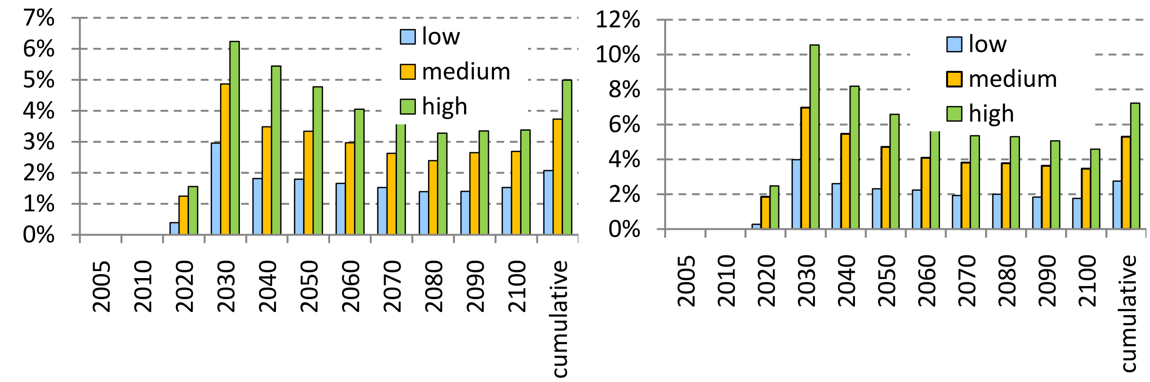

Figure 7: Contribution of demand reduction to overall emission reduction in the USA (left) and Western Europe (right)

A major difference between the USA and Western Europe in the model is that the contribution of demand reduction is significantly higher in Western Europe (Figure 7). While it is 2.8% in the medium scenario for the USA, it amounts to 4% for Western Europe. This can be explained with cheaper mitigation options that exist in the USA compared to Western Europe. This again has an influence on the price for the energy service demand, which is higher in Western Europe and therefore triggers higher demand reductions.

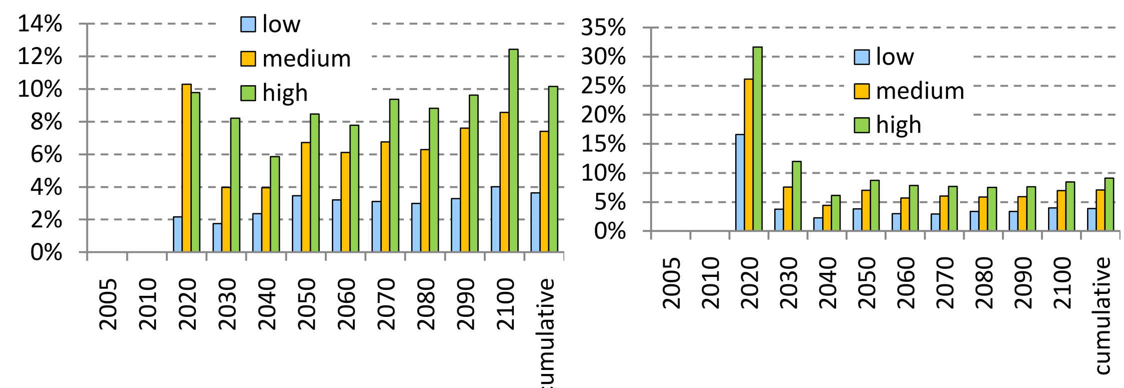

Figure 8: Contribution of demand reduction to overall emission reduction in India (left) and China (right)

Compared with the developed countries, Figure 8 highlights that the demand reduction plays a more important role in India and China. Here, the cumulative contribution of demand reduction in the medium scenario is at 6.6% for India and 6.2% for China. The demand reduction is a quarter for China in 2030, though as the overall CO2 reduction in China 2030 is rather low, this is not reflected in the cumulative figure. Interesting to note is that the role of demand reduction in India tends to increase over time and is more sensitive to the assumed demand elasticity compared to China.

<u>Global sectoral contribution</u>

A look on the sectoral level can reveal insights into the importance of demand reduction at a more detailed level. In this case, emissions from second energy carriers, such as electricity, are accounted for in the end-use sectors. Figure 9 points out that demand reduction is particularly important in the decarbonisation of the transport sector. In the medium elasticity scenario 15.8% of the total mitigated CO_2 emissions are due to demand reduction in the transport sector, the respective figure is 2.4% in the residential sector. An explanation is the relatively high cost mitigation opportunities in the transport sector, as e.g. electric vehicles, increased share of biodiesel, compared to the residential sector, where relatively cheap abatement options exist in the form of house insulation or increases in the efficiency of boilers. In the years 2030 and 2040 the share of demand reduction in the transport emission reduction is very high (up to 30%), while the contribution of transport sector to total emission reduction is very low during that period.

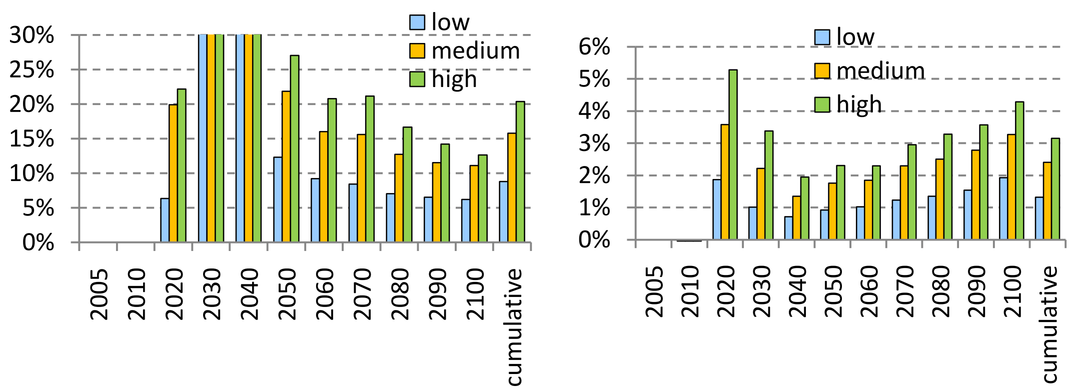

Figure 9: Contribution of demand reduction to overall emission reduction in the transport sector (left) and residential sector (right)

Implications of demand reduction

The elastic demand version of TIAM-UCL decreases the marginal CO_2 abatement costs compared to the standard version of the model (Figure **10**). As expected marginal abatement cost decreases when the elasticity is increased. Marginal abatement cost in 2050 is 337 US\$/t-CO_2 in LCD-STD and 219 US\$/t-CO_2 in LCD-HED. Respective figures for 2100 are 512 and 418 US\$/t-CO_2.

The regional share in global emissions under different low carbon scenarios in 2050 and 2100 are presented in Figure **11**. It is based on the actual emissions (without trading) emitted by each region. Modelling results show that demand reduction, as a response to price changes, influences the regional CO_2 mix. It is more visible in 2100 (Figure **11**). For example, the share of China in the residual CO_2 emissions decreases under elastic demand scenarios (LC-LED, LC-MED and LC-HED) in 2050 and 2100 as compared to the standard version, where the energy services demand is fixed, while the share of India decreases in 2050 and increases in 2100. China and the USA have their lowest share in the residual emissions when the demand elasticity is high, where India and Africa have their highest share, in 2100. Contribution to residual emissions under different elasticity scenarios are affected by level of emission trading beside the technical factors. At the lowest level of elasticity, contribution of demand reduction to meet the CO_2 mitigation target is limited, domestic mitigation becomes expensive in China leading it to buy more emission credits in the international market. Then it is economic for sellers like India and Africa to mitigate more than the target as they benefit by selling credits to China especially in 2100. In contrast, at the highest level of elasticity, India emits more than the target as it is economic to buy cheaper credits available in the market to meets its target as China demands less credits in the market.

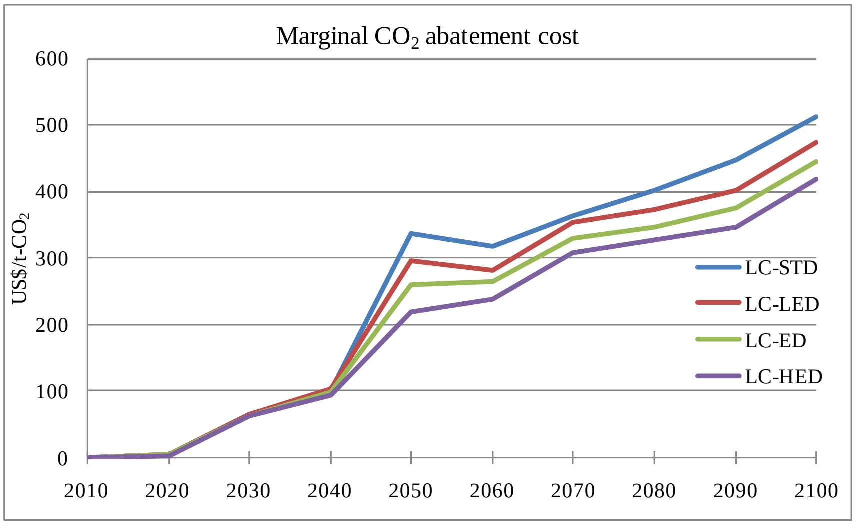

Figure 10: Marginal CO_2 abatement cost under different scenarios

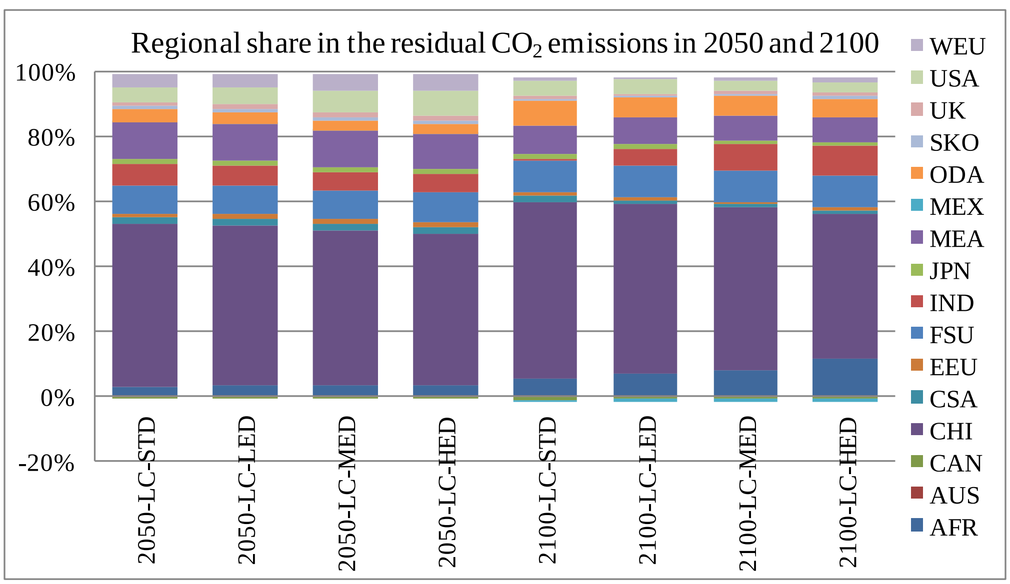

Figure 11: Regional share in the residual CO2 emissions in selected years

Figure **12** shows the global discounted energy system cost and cost of demand reduction. Though demand reduction reduces energy system costs it needs a behavioural change as well as it costs the society in terms of welfare losses due to the un-served energy services demand. Analyses show that cost of demand reduction doubles between the low and high elasticity scenarios.

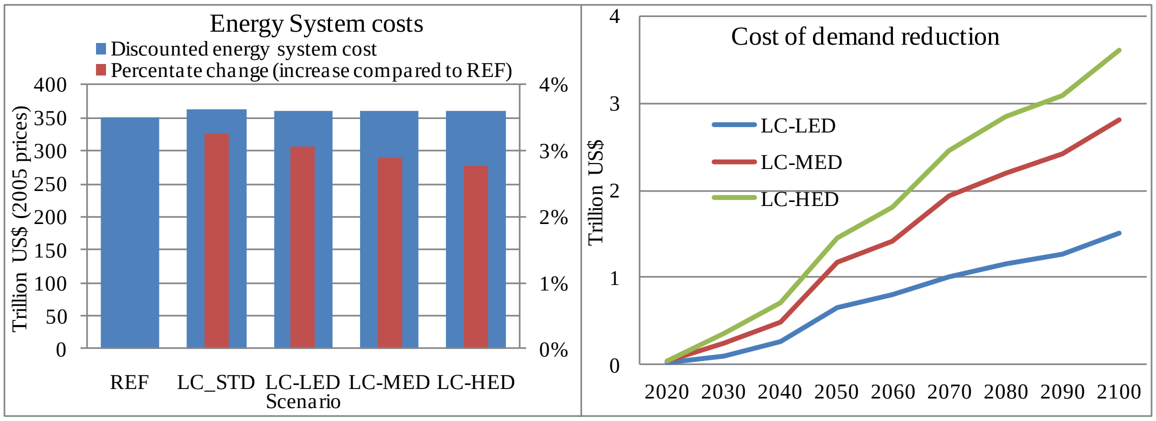

Figure 12: Energy system cost and cost of demand reduction under different scenarios

Conclusion

This paper examined the role of demand reduction in meeting the global climate change mitigation target. Logarithmic mean Divisia index (LMDI) decomposition technique has been used to decompose the results of the TIAM-UCL global energy system model in its elastic demand version, which has been used under different long-term low carbon energy scenarios through to 2100 at low, medium and high values for demand elasticity.

Demand reduction level varies across sectors and scenarios and it is sensitive to demand elasticity. Analysis shows that developing countries like China and India experience higher demand reduction in industry sector while developed countries experience higher demand reduction in non-road transport.

A key finding is that demand reduction can play a significant role within a limited scope next to more important measures, in particular structural shifts towards carbon-free energy technologies. According to the model results, demand reduction contributes between 3-7% to overall CO_2 emission reduction on a global level throughout the 21^{st} century. At the sectoral level, it plays a significant role for selected energy services demands especially in the transport sector contributing around 16%, while it is insignificant in the residential and commercial sector. Contribution of demand reduction is higher in early period as the cheaper low/zero carbon technologies are not ready yet in the early period.

Another interesting finding is that demand reduction can greatly affect the regional emission mix. In 2100, China and the USA have their lowest share in the residual emissions when the demand elasticity is high, where India and Africa have their highest share. Contribution to residual emissions under different elasticity scenarios are affected by the level of emission trading next to technical factors.

Demand reduction needs behavioural changes, which comes as an expense to society in terms of welfare losses due to the un-served energy services demand. Analysis shows that the cost of demand reduction doubles between the low and high elasticity scenarios costing US$1.5 trillion in the LC-LED scenario and US$3.6 trillion in the LC-HED scenario in 2100.

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