Re-thinking the Importance of Equity Principles in Carbon Emissions Policy for the Future: A Policy Driven Empirical Narration for India vs. European Union[1]

Sovik Mukherjee[2]

Abstract

The concept of justice and being "fair" is often heavily debated, more so, when it comes to the international negotiations on the mitigation of climate change. A peep into the charter of the UN Framework Convention on Climate Change highlights the importance of distributive fairness or in other words, equity. The concepts of "equal per capita CO_2 emissions", "polluter-pays principle" etc., in some way provide different perspectives on the issue of equity. For a long time, economics literature has been focussing on the efficient allocation of optimum levels of the provision of some common resources amongst different associated parties. But strangely, less attention has been given to the equity aspects of such allocations.

In this backdrop, out of the existing equity criteria, i.e. *egalitarian rule*, *sovereignty rule*, *polluter-pays rule*, *ability-to-pay rule*, the first objective is to quantify the significance of these equity principles across two major power houses in the world at present, India and the European Union (EU) in 2014–15 (actual) and in terminal years of 2021–22 and 2031–32 for the future. To assess the distributions implied by the egalitarian, sovereignty, polluter-pays, and ability-to-pay rules, the paper makes use of the trends in the respective countries' or groups of countries' population data, baseline carbon emissions, and GDP against two sets of scenarios, the BAU Scenario (Business as Usual) and the Accelerated Scenario (i.e. with a 30 per cent CO_2 emissions reduction). The recommendation is that the EU should design its

1 This research work was supported by a research grant (File No. CON/518/2018-ICS) from the Indian Council of Social Science Research (ICSSR) awarded to Sovik Mukherjee.

2 Department of Economics, Faculty of Commerce and Management Studies, St. Xavier's University, Kolkata, India.

emissions reduction policy in line with the ability-to-pay rule while for India it should be the egalitarian rule.

Keywords:
Accelerated Scenario, Business as Usual (BAU), Co-integration, Equity, CO_2 emissions policy

1. Goal

Defining an internationally equitable distribution of the burdens of reducing climate change risks has been a basic concern for as long as greenhouse gas (GHG) emissions policies have been debated. Countries clearly differ greatly in terms of their vulnerability to climate change, for example, developing countries as well as environmental interest groups in industrialised countries claim that developed countries with high per capita greenhouse gas emissions are responsible for global warming and must take the lead in combating climate change. In consequence, weaker obligations for developing countries may be based on equity arguments.

The main objective of trying out such an exercise is to predict the decision-making authority's future choice of equity principle after weighing the benefits and costs arising out of such equity principles. The results indicate that in the long run, the polluter-pays principle becomes comparatively insignificant. However, when it comes to the CO_2 emissions abatement, as already existing in the literature, the support for egalitarian principle comes from developing countries. Furthermore, the novelty of my contribution lies in the formulation of a convex combination of all the four equity principles to see the relative effectiveness of such principles across these two power houses.

2. Target Group

Though I have taken into consideration only the European Union and India, the target group comprises the audience from the "Big Four", *viz.*, the United States, European Union, China, and India and the policymakers who decide on which equity principles or criteria are to be applied.

3. Policy Aims

In view of the climate emergency in terms of carbon emissions, the target is to reach a reduction in carbon emissions of at least 30–40 per cent by 2030–31 to control the global warming and limit it to 1.5 °C. In the process of implementing the policy recommendations in the context of international climate policy, both the EU and

India, being a negotiating party, may be predicted to use those equity arguments which lead to relatively lower costs.

4. Background

Bargaining situations and negotiations frequently resemble striving for fairness when bargainers feel that they are in a disadvantaged position to receive their "fair share". But the meaning of "fair" is often heavily debated. The perception of fairness may, however, differ across the involved parties. Several strands of economic, as well as psychological literature, indicate that the understanding of what is fair is – at least to a certain extent – driven by the economic costs of the respective equity rules: Babcock et al. (1996) consider a "self-serving bias in judgments of fairness" in an experimental bargaining situation. This notion of self-serving biases usually refers to unconscious distortions in perceptions of fairness. In contrast, our paper establishes a self-interested use of equity which includes potentially intentional distortions of equity beliefs. Babcock and Loewenstein (1997) review psychological and experimental evidence for this interaction between material payoffs and fairness perceptions. Self-serving social comparisons from teacher contract negotiations are discussed by Babcock et al. (1996). In a different approach, Hennig-Schmidt (2002) shows the self-interested use of equity arguments in a video-bargaining experiment. If conflicting principles of fairness are part of the negotiation process, a potential agreement requires weighing and reconciliation of the different proposed equity bases. Moving on, Bosello et al. (2001) study the stability of international agreements if they are based on a single equity rule but do not find major improvements in the relatively pessimistic predictions from traditional economic models of coalition formation (Carraro & Siniscalco, 1993). Böhringer and Helm (2008) consider an axiomatic approach of fair division and calculate the burden resulting from such an allocation mechanism. Lange and Vogt (2003) and Lange (2006) take a different approach and model preferences which trade-off payoffs with equity concerns. Such equity preferences may potentially increase cooperation rates but are based on the assumption that countries evaluate their position based on a single given equity criterion.

In this backdrop, negotiations thus become more complicated when there is more than one justifiable fairness norm (Raiffa, 1982). Now what negotiators do is potentially choose those fairness principles in line with their demands and not in line with the equity principles. Herein lies the conflict. In spite of the graveness of the situation, the actual role of equity principles in shaping negotiation processes has received only limited attention in the literature. Several studies identify different typologies of equity principles. This paper follows Lange et al. (2010) and primarily focuses on the dominating principles in the context of international climate policy, such as, egalitarian rule, sovereignty rule, polluter-pays rule, ability-to-pay rule. The issue of equity principles in the context of CO_2 emissions assumes a critical position.

This happens on account of the claim that developing countries have regarding developed countries with high per capita greenhouse gas emissions being responsible for taking a lead in global warming. Often, similar emission reduction targets are seen as fair, based on present or recent emission levels (Cazorla & Toman, 2001).

The concept of justice and being "fair" is often heavily debated, more so, when it comes to the international negotiations on the mitigation of climate change. A peep into the charter of the UN Framework Convention on Climate Change highlights the importance of distributive fairness or, in other words, equity. The concepts of "equal per capita CO_2 emissions", "polluter-pays principle", etc. in some way provide different perspectives on the issue of equity. Out of the existing equity criteria, i.e. *egalitarian rule*, *sovereignty rule*, *polluter-pays rule*, *ability-to-pay rule*[3], the first objective is to compare the feasibility as to what extent the equity principles can be incorporated into the carbon emissions policy for the future, in line with IPCC's predictions that global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate of 0.8°C – 1.2°C (IPCC, 2018).

In Nash's (1950) seminal work on bargaining, all differences between the players were supposedly captured in the disagreement point and the shape of the bargaining set. Many other explanations for bargaining power have been suggested since then – not least the differences in time or risk preference (Roth, 1979). However, if one follows many negotiation processes, the concept most parties follow is the "fairness" argument in order to convince the other party to agree to their demands. The payoff to a player in these (axiomatic) solutions increases in their legal claim. Recently, Gächter and Riedl (2005) studied the effects of "moral property rights" on bargaining. Here, individual views on fairness inform the bargaining situation and thereby influence the bargaining outcome. That is, the entitlements or individual claims are not given by some (incompatible) legal property rights but by what bargainers perceive as a fair agreement. Similar to these approaches, the frequency of equity arguments in negotiations indicates that there is an interaction between bargaining power, i.e. the ability to influence the negotiation outcome favourably, and the availability of equity arguments: for example, if all equity criteria required that a negotiating party receives a larger share of the surplus, this party would be likely to be able to influence the bargaining outcome in its favour. Conversely, the lack of an equity or fairness argument for one's position would, in our view result in a reduction of bargaining power. The end result of negotiations may thus hardly

3 This rule incorporates the principle of equal per capita emissions: egalitarian rule (EGA).

This rule incorporates the principle of equal percentage reduction of current emissions: sovereignty rule (SOV).

This rule incorporates the principle of equal ratio between abatement costs and emissions: polluter-pays rule (POL).

This rule incorporates the principle of equal ratio between abatement costs and GDP: ability-to-pay rule (ABI).

be understood without analysing the underlying equity principles and their use by the respective parties.

There is substantial evidence that individual perceptions of "what is fair" are correlated with the economic costs and benefits implied by the respective equity criteria (for instance, Babcock & Loewenstein 1997, Dahl & Ransom, 1999). These differing perceptions are also apparent in the use of equity principles as arguments in bargaining processes (Hennig-Schmidt, 2002). This could be the case for two reasons: (i) a self-serving bias, i.e. individuals might *subconsciously* interpret fairness in a way that benefits their interests, or, (ii) a *conscious* decision on self-interested use of equity, i.e. individuals might use specific fairness notions to consciously pursue their own interest while exploiting the others' sense of justice (see for details Konow, 2001). Also, in papers like Messick and Sentis (1979), Thompson and Loewenstein (1979) evidence for the subconscious self-serving bias has been found while Dahl and Ransom (1999) and Gächter and Riedl (2005) find relatively little evidence in this regard. In either way, a self-interested perception and/or use of equity is essential in explaining bargaining outcomes if a party successfully influences the bargaining process in its favour by referring to equity arguments.

5. A Comparison of the Economic Costs of different Equity Principles

To begin with, the paper generates predictions on the four different equity criteria the respective parties would prefer in their own self-interest by comparing the distribution of costs under the "burden sharing of abating carbon emissions" (Lange et al., 2007) in line with the equity rules. I assume that the aggregate emissions target is exogenous and for any given overall target (or equivalently, any given marginal abatement costs), the different equity criteria therefore implies a specific distribution of costs and benefits. In order to assess the distributions implied by the egalitarian, sovereignty, polluter-pays, and ability-to-pay rules, we use information on abatement costs in the respective countries, their population data, baseline carbon emissions, and GDP levels and set up the BAU Scenario (Business as Usual) and the Accelerated Scenario (i.e. with a 30 per cent CO_2 emissions reduction).

5.1 Constructing the Research Hypothesis

The projections for GDP, CO_2 emissions (both lifecycle and current) and populations for 2021–22 and 2031–32 have been discussed in detail in the appendix section. Coming to the methodology of calculating the emissions distribution under these equity principles, I have framed the equity principles as follows,

$$EGA : \frac{Emissions_t}{Population_t}$$

$$SOV : \frac{Emissions_t - Abatement_t}{Emissions_t}$$

$$POL : \frac{Abatement_t}{Emissions_t}$$

$$ABI : \frac{Abatement\ Costs_t}{GDP_t}$$

for the t^{th} year for the j^{th} country, where j = {India, European Union}

Marginal abatement cost curves for 2021–22 are generated based on estimates derived from the energy demand model in the appendix (see also POLES model[4]). Table 1contains all relevant data on the projected marginal costs and subsequently the projected costs under the different equity criteria for both the BAU scenario and the accelerated scenario. I now develop a quantitative model for the projection of growth of the future demand for energy of the Indian economy and Eurozone which would support certain basic economic targets in terms of carbon emissions. We describe in Table 1 the abatement costs under different equity conditions of the model of projection of electricity requirement or demand and supply. All scenarios assume 8 per cent overall GDP growth and alternative rates of energy conserving technical change and that of the introduction of carbon free new renewable fuels targeted at 30 per cent reduction of emissions.

4 See the methodology of POLES Model at https://www.enerdata.net/solutions/poles-model.html

6. Results and Discussions

Table 1
Calculation of Abatement Costs

Accelerated Scenario					
	Emission reduction costs: (USD2000/tc)#				
	40 tc	80 tc	120 tc	160 tc	200 tc
	Total abatement costs (Bn USD2000)				
2021-22					
EU	1.4	4.7	9.4	15.0	21.2
India	9.5	30.7	58.2	89.9	124.7
2031-32					
EU	1.6	7.8	16.2	25.5	36.9
India	17.2	50.5	87.1	125.4	160.1
BAU Scenario					
	Emission reduction costs: (USD2000/tc)#				
	40 tc	80 tc	120 tc	160 tc	200 tc
	Total abatement costs (Bn USD2000)				
2021-22					
EU	0.9	2.4	7.4	11.3	19.1
India	5.5	24.7	50.9	81.1	110.3
2031-32					
EU	1.1	5.4	10.3	19.5	30.4
India	10.1	37.9	78.8	112.6	145.2

Source: Author's own computations based on the energy demand model in the appendix

#tc: tonnes of carbon per year

What are the overall implications of the projection of such abatement costs at different levels of marginal technology based plants on the one hand, and in terms of CO_2 emission implications on the other. These would indicate the relative physical benefit and financial cost of CO_2 emission reductions under the normal BAU scenario and under the accelerated scenario with 30 per cent emissions reduction. Table 1 shows that the abatement costs reduction is more under the accelerated scenario with a provision of 30 per cent emissions reduction. Table 2 provides the normative CO_2 emission coefficients — current as well as life cycle ones for the different generation technologies for India. However, for the EU, there is an overall coefficient as the technology-wise breakup is not available. These coefficients have been assumed for the current emission to be as per CEA norm and that for the life cycle emission to be as per IPCC norms for the generation technologies. It should be noted that, at first, the levels of CO_2 emissions were calculated by multiplying the technology wise gross generation with the normative coefficients in Table 2. This is followed by calculating the abatement costs at different levels, namely, (40, 80, 120, 160, 200 USD2000/tc) of emissions reduction.

Table 2

CO_2 emission coefficients (current and lifecycle)_India

Fuels	Current	Lifecycle
Coal	1.04	0.820
Gas	0.60	0.490
Nuclear	0	0.012
Hydro storage	0	0.024
Solar PV	0	0.048
Solar CSP	0	0.048
Distributed Solar PV	0	0.048
Total Solar	0	0.048
Onshore Wind	0	0.012
Offshore Wind	0	0.012
Total Wind	0	0.012
Other Renewables	0	0.230

Source: Compiled by the author from IEA database and World Bank database

Note: For the European Union we do not have a detailed break-up available, so we make use of the components (whichever are applicable) and the total value of the coefficients on the whole.

Table 3
Projected costs for the terminal years of 2021–22 and 2031–32 implied by the respective equity criteria for the respective countries or groups of countries (in per cent of GDP) when marginal abatement costs are equalised at 80 USD2000/tC, corresponding to a worldwide reduction from BAU emissions by 30 per cent

Accelerated Scenario				
	Different Equity Criteria			
	EGA	SOV	POL	ABI
2021-22				
EU	0.323	0.055	0.062	0.049
India	−0.473	0.044	0.055	0.059
2031-32				
EU	0.298	0.050	0.057	0.049
India	−0.512	0.045	0.060	0.069
BAU Scenario				
	Different Equity Criteria			
	EGA	SOV	POL	ABI
2021-22				
EU	0.301	0.049	0.058	0.045
India	−0.422	0.039	0.051	0.052
2031-32				
EU	0.255	0.044	0.053	0.040
India	−0.467	0.040	0.054	0.064

Source: Author's own calculations

7. Stakeholder Analysis

7.1 For the European Union

These would indicate the relative physical benefits and financial costs of CO_2 emission reductions under the different equity criteria. Table 2 provides the normative CO_2 emission coefficients — current as well as life cycle ones for the different generation technologies under both the BAU scenario and the accelerated scenario. These coefficients have been assumed for the current emission to be as per CEA norm and that for the life cycle emission to be as per IPCC norms for generation technologies. Interestingly, the rankings of the four equity principles as per their cost effectiveness under both the scenarios remain the same. The egalitarian rule has the maximum cost; thus, it is realistically not applicable as there is no guarantee of an equal distribution. Given the comparatively larger amount of emissions between 1860 and 2020 in the EU, the polluter-pays principle, based on the cumulated carbon emissions, would also be very costly for the EU (see Table 3). This is followed by the sovereignty rule and relatively the least cost wise, the ability-to-pay principle. Given the EU's combined GDP and the sharing of abatement costs, ABI is very possible. The ranking goes as follows,

ABI > SOV > POL > EGA

8.2 For India

We now discuss the costs which are implied by the different equity rules for India. The ranking of equity criteria – given by the cost projections as reported in Table 3 are as follows:

EGA > SOV > POL > ABI

It is evident that India, with its large share in global population, would profit most from a strict application of the egalitarian principle. This again goes against the policies of the EU as given the level of population in EU, its per capita emissions would not go down to that extent as compared to that of India. India has a clear advantage in the context of EGA. In contrast, India would oppose a support of the polluter-pays and the ability-to-pay principles on the basis of their respective costs. The latter principle refers to the predicted high economic growth of India in the terminal years which would raise the costs associated with the ability-to-pay rule. Going by the ability-to-pay principle, the idea is to equalise abatement costs across nations. This principle would benefit the EU but would hurt India, given the level of abatement costs as a proportion of its GDP and net cost proportions being inversely correlated relative to economic circumstances. Also, the polluter-pays principle is based on the predicted large increase in emissions from India over the next decades so that the costs of the polluter-pays rule would be increased. Again, from this 30 per cent accelerated scenario, comparatively, India has the capability to reduce it further if it goes by any of the four equity principles. Interestingly, going by SOV i.e. reducing the level of current emissions proportional to the level of total historical emissions across all countries is a good option for India but given the relative cost considerations, the EU might not support it.

8. Policy Implications

In all probability, adopting a multi-criteria approach and setting it as per 'one-size-fits-all' is not always wise. Countries will then look to see how a specific formula affects their self-interest and then fight it out in the Climate Change Conventions. However, India would be able to increase her national emissions significantly before reaching the population-to-emissions ratio limit because of the large and rapidly growing populations and rapid economic growth. As Agarwal (2015) puts it, India has said it aims to reduce the emissions intensity of its GDP by 33–35 per cent by 2030 from 2005 levels, and achieve 40 per cent of its cumulative electric power of around 350 GW installed capacity from non-fossil fuel-based energy resources, mainly renewable power. There are mixed responses. While some experts welcomed India's submissions stating that India's climate action plan is far superior to those proposed by the US and the European Union (EU), others said it does not fully capture the emissions it would avoid if it succeeds in meeting its renewable energy goals.

By the same token, however, allocating emission limits based on historical emissions conveys a huge advantage to the developed world, given their historically overwhelming share of emissions in GDP. So, in such a case, India will not support the ABI principle (see Table 3 for the cost effectiveness criteria). Simply extending this approach to the developing countries limits their incentives to pursue modest "win-win" emissions control in the short term, for fear that doing so would put them on a lower emissions bound and they will not be able to fight for increasing the level of emissions in future negotiations. Strategically, it is the prerogative of the policy-makers to take care of the extent of abatement costs under the different equity principles and frame policies accordingly.

As expected, given the cost in Table 3, the EU in 2031–32 as per the different equity principles, has an opportunity to reduce more emissions in line with its INDC submitted to the UNFCCC, outlining its mitigation contribution of at least 40 per cent emission reduction through domestic efforts by 2030 below its 1990 levels. Given the cost considerations are on the lower side (not to the extent, like India) this target is very feasible as per the predictions of my model.

9. Concluding Remarks

In this paper, we put forward equity as an important element to understanding negotiating positions, using the example of international climate negotiations. Taking a traditional economic standpoint, we argued that the use of equity criteria might be driven by cost consideration of the parties. Our econometric analysis, based on data from an international survey of agents involved in climate policy, largely supported our predictions based on a cost-ranking of the respective equity criteria for the different countries or groups of countries: the perceived support of equity criteria is the stronger, the less costly this criterion is compared to alternatives.

At first, I used the data in order to establish that countries or groups of countries are seen as pushing for different equity criteria in international climate negotiation forums and not agreeing to any one in particular. Their negotiating positions are highly affected by the induced abatement costs. The differences in perceptions across the agents involved in international climate policy will establish support for versions of self-interested biases in line with the different equity principles. The exact question is how exactly these countries use their influences in the negotiation process to turn the policy towards them. To end with, it is my belief that this potentiality of the strategic role of using equity criteria will be gaining more importance in the near future for generating a better understanding of negotiation processes – not only in international climate policy but also for India and the EU, in particular.

Many climate scientists believe that the equity problem is a property rights problem, —how rights to emit GHGs are to be allocated. Critics claim that there is no hope for solving this never ending problem. Nevertheless, there is definitely a way out for this, provided that both the developed and the developing countries continue to develop relationships that will support this long-term commitment of sharing benefits arising out of reduction in CO_2 emissions in a mutually agreeable fashion.

References

Agarwal, M. (2015). *India pledges 33–35per cent cut in carbon emission intensity by 2030.* Retrieved from https://www.livemint.com/Politics/ZD2z2vwZktGNlzhrLujmyO/India-unveils-emission-targets-for-2030-in-UN-climate-submis.html

Babcock, L., Wang, X., & Loewenstein, G. (1996). Choosing the wrong pond: Social comparisons in negotiations that reflect a self-serving bias. *The Quarterly Journal of Economics*, *111*(1), 1–19.

Babcock, L., & Loewenstein, G. (1997). Explaining bargaining impasse: The role of self-serving biases. *Journal of Economic Perspectives*, *11*(1), 109–126.

Böhringer, C., & Helm, C. (2008). On the fair division of greenhouse gas abatement cost. *Resource and Energy Economics*, *30*(2), 260–276.

Bosello, F., Buchner, B., Carraro, C., & Raggi, D. (2001). *Can equity enhance efficiency?: lessons from the Kyoto protocol*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.202.1933&rep=rep1&type=pdf

Carraro, C., & Siniscalco, D. (1993). Strategies for the international protection of the environment. *Journal of Public Economics*, *52*(3), 309–328.

Cazorla, M., & Toman, M. (2001). International equity and climate change policy. Retrieved from https://pdfs.semanticscholar.org/533f/53cd3e570d7e2ae712373d479b1f2a1b2158.pdf

Dahl, G. B., & Ransom, M. R. (1999). Does where you stand depend on where you sit? Tithing donations and self-serving beliefs. *American Economic Review*, *89*(4), 703–727.

Engle, R. F., & Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica*, *55*(2), 251–276.

Gächter, S., & Riedl, A. (2005). Moral property rights in bargaining with infeasible claims. *Management Science*, *51*(2), 249–263.

Hennig-Schmidt, H. (2002): The Impact of Fairness on Decision Making – An Analysis of Different Video Experiments, in: Andersson, F. and H. Holm (eds.), Experimental Economics: Financial Markets, Auctions, and Decision Making, Kluwer Academic Publishers, Boston, Dordrecht, London, 185–210.

Lange, A. (2006). The impact of equity-preferences on the stability of international environmental agreements. *Environmental and Resource Economics*, *34*(2), 247–267.

Lange, A., Löschel, A., Vogt, C., & Ziegler, A. (2010). On the self-interested use of equity in international climate negotiations. *European Economic Review*, *54*(3), 359–375.

Lange, A., & Vogt, C. (2003). Cooperation in international environmental negotiations due to a preference for equity. *Journal of Public Economics*, *87*(9–10), 2049–2067.

Lange, A., Vogt, C., & Ziegler, A. (2007). On the importance of equity in international climate policy: An empirical analysis. *Energy Economics*, *29*(3), 545–562.

Konow, J. (2001). Fair and square: the four sides of distributive justice. *Journal of Economic Behavior & Organization*, *46*(2), 137–164.

Messick, D. M., & Sentis, K. P. (1979). Fairness and preference. *Journal of Experimental Social Psychology*, *15*(4), 418–434.

Nash, J. F. 1950. *The bargaining problem. Econometrica*, *18*(2), 155–162.

Raiffa, H. (1982). *The art and science of negotiation*. London: Harvard University Press.

Roth, A. E. (1979). An impossibility result concerning-person bargaining games. *International Journal of Game Theory*, *8*(3), 129–132.

Thompson, L., & Loewenstein, G. (1992). Egocentric interpretations of fairness and interpersonal conflict. *Organizational Behavior and Human Decision Processes*, *51*(2), 176–197.

Appendix

For analysing the energy consumption behaviour at sectoral level and overall economy level, I propose a simple model, which assumes that the demand for energy (EDD^i) of each sector i of the economy is a function of its income (I^i) and the real energy price it faces. The partial income elasticity of demand and the partial price elasticity are assumed to remain constant over the projections period. This gives us a demand function of the form-

$$EDD^i = A(I^i)^\alpha (RPE^i)^\beta ,$$

where i = Overall economy, agriculture, industry, residential, commercial and transport sectors.

Here,

α, is the income elasticity of energy demand

β, is the price elasticity of energy demand

A, is the technology parameter

α β, and A are constant over the entire projection period.

For the purpose of econometric estimation the above model can be transformed into a double log linear model of the form-

$$\log(EDD_t^i) = \log(A) + \alpha * \log(I_t^i) + \beta * \log(RPE_t^i) + \varepsilon_t^i$$

ε_t^i, is the random error component and conforms to the assumptions of the classical regression model

Data and Sources

The econometric estimation of the model for the overall economy and for each sector requires data on energy demand, GDP that indicates the level of income or value added and the real energy price index. The nominal energy price is calculated using the fuel shares and the corresponding WPI of fuels faced by a given sector or by the aggregate economy. The real energy price is calculated by deflating the nominal price by the GDP deflator. The Private Final Consumption (PFCE) is used as an indicator of income for the residential sector. The model is estimated using data from 1990–2015. The data for energy demand is obtained from the Energy Balances of the non-OECD countries published by the International Energy Agency (IEA), the IEA database and Eurostat database for the European Union. The data for GDP and PFCE for India are obtained from the National Account Statistics, and the data for WPI prices are obtained from the RBI database (Handbook of Statistics on the Indian Economy) and the website of the Office of the Economic Advisor. Also, for the European Union data on GDP and Gross Fixed Capital Formation, we make use of the Eurostat database.

Estimation

We begin by applying the standard time series techniques. First to check the stationarity of the data we go for Augmented Dickey Fuller Test, the results of which have been reported in Table A1.

Given the unit root results and the order of integration, we estimate the following model,

$$\log(\Delta ED_0) = \beta \log(\Delta GDP_0) + \gamma \log(REP_0)$$

It needs that the sectoral GDP and the final energy demand of the concentrated sectors are integrated of the second order whereas the real energy prices faced by each of the sectors are integrated of order 1. For applying the Engel and Granger (1987) methodology of co-integration in single equation specification, we consider the following model,

$$\log(\Delta ED_i) = \beta log(\Delta GDP_i) + \gamma \log(REP_i) + \epsilon \qquad where\ i = A, I, T, R, C \quad and$$

ΔED_i is the change in the energy demand of the i^{th}sector, integrated of order 1.

ΔGDP_i is the change in GDP of the i^{th} sector, integrated of order 1.

REP_i is the real energy price faced by the i^{th} sector, integrated of order 1.

The co-integration results deriving the long run elasticity coefficients of sectoral energy demand and real energy price of different sectors have been reported in Table A2.

In order to project the final energy demand at the original level, we make use of the following derivation,

$$\log(\Delta ED_t) - \log(\Delta ED_0) = \beta[\log(\Delta GDP_t) - \log(\Delta GDP_0)] + \gamma[\log(REP_t) - \log(REP_0)]$$

$$\frac{\Delta ED_t}{\Delta ED_0} = \left(\frac{\Delta GDP_t}{\Delta GDP_0}\right)^{\beta} \times \left(\frac{REP_t}{REP_0}\right)^{\gamma}, t = 2015, 2016, \dots \dots, 2041$$

$$or, \qquad \Delta ED_t = \left(\frac{\Delta GDP_t}{\Delta GDP_0}\right)^{\beta} \times \left(\frac{REP_t}{REP_0}\right)^{\gamma} \times \Delta ED_0 \qquad \dots \dots \dots (1)$$

Now, projecting the energy demand at 2021, we

Calculate (1) for t = 2015, 2016, 2017, 2018, 2019, 2020, 2021 and then add up these to obtain the total change from 2014–2021 and finally add it up with the base year value of 2014 to derive the final energy demand in the concerned year.

Similarly, we do it for 2031–32.

Table A1

Unit Root results

Variables (order of integration)	Augmented DF test statistic	Probability
INDIA		
INDUSTRY_GDP (2)	−5.28	0.00*
INDUSTRY_Energy Demand (2)	−6.38	0.00*
INDUSTRY_Real Energy Price (1)	−6.11	0.00*
AGRICULTURE_GDP (2)	−13.37	0.00*
AGRICULTURE_Energy Demand (2)	−6.72	0.00*
AGRICULTURE_Real Energy Price (1)	−6.23	0.00*
RESIDENTIAL_GDP (2)	−6.46	0.00*
RESIDENTIAL_Energy Demand (2)	−5.26	0.00*
RESIDENTIAL_Real Energy Price (1)	−6.20	0.00*
COMMERCIAL_GDP (2)	−5.69	0.00*
COMMERCIAL_Energy Demand (2)	−9.16	0.00*
COMMERCIAL_Real Energy Price (1)	−6.24	0.00*
TRANSPORT_GDP (2)	−4.34	0.01*
TRANSPORT_Energy Demand (2)	−5.46	0.00*
TRANSPORT_Real Energy Price (1)	−6.27	0.00*
OVERALL_GDP (2)	−6.33	0.00*
OVERALL_Energy Demand (2)	−7.12	0.00*
OVERALL_Real Energy Price (1)	−4.23	0.01*
EUROPEAN UNION		
INDUSTRY_GDP (2)	−6.81	0.00*
INDUSTRY_Energy Demand (2)	−6.44	0.00*
INDUSTRY_Real Energy Price (1)	−5.97	0.00*
AGRICULTURE_GDP (2)	−11.3	0.00*
AGRICULTURE_Energy Demand (2)	−5.72	0.00*
AGRICULTURE_Real Energy Price (1)	−4.66	0.00*
RESIDENTIAL_GDP (2)	−7.61	0.00*
RESIDENTIAL_Energy Demand (2)	−5.26	0.00*
RESIDENTIAL_Real Energy Price (1)	−5.30	0.00*
COMMERCIAL_GDP (2)	−5.98	0.00*
COMMERCIAL_Energy Demand (2)	−8.21	0.00*
COMMERCIAL_Real Energy Price (1)	−7.42	0.00*
TRANSPORT_GDP (2)	−5.44	0.01*
TRANSPORT_Energy Demand (2)	−6.21	0.00*
TRANSPORT_Real Energy Price (1)	−7.71	0.00*
OVERALL_GDP (2)	−5.83	0.00*
OVERALL_Energy Demand (2)	−8.22	0.00*
OVERALL_Real Energy Price (1)	−7.11	0.01*

* denotes significance at 95 per cent level

Table A2
Long run elasticity coefficients results

Variables (logarithm)	Elasticity Coefficients	Probability
INDIA		
Dep Var: Δ (INDUSTRY_Energy demand)		
Δ (INDUSTRY_GDP)	0.83	0.00*
INDUSTRY_Real Energy Price	0.03	0.00*
Dep Var: Δ (AGRICULTURE_Energy demand)		
Δ (AGRICULTURE_GDP)	0.75	0.00*
AGRICULTURE_Real Energy Price	0.12	0.06
Dep Var: Δ (RESIDENTIAL_Energy demand)		
Δ (RESIDENTIAL_GDP)	0.72	0.00*
RESIDENTIAL_Real Energy Price	–0.02	0.00*
Dep Var: Δ (COMMERCIAL_Energy demand)		
Δ (COMMERCIAL_GDP)	0.62	0.00*
COMMERCIAL_Real Energy Price	–0.38	0.00*
Dep Var: Δ (TRANSPORT_Energy demand)		
Δ (TRANSPORT_GDP)	0.88	0.00*
TRANSPORT_Real Energy Price	–0.08	0.00*
EUROPEAN UNION		
Dep Var: Δ (INDUSTRY_Energy demand)		
Δ (INDUSTRY_GDP)	0.78	0.00*
INDUSTRY_Real Energy Price	0.06	0.00*
Dep Var: Δ (AGRICULTURE_Energy demand)		
Δ (AGRICULTURE_GDP)	0.61	0.00*
AGRICULTURE_Real Energy Price	0.09	0.06
Dep Var: Δ (RESIDENTIAL_Energy demand)		
Δ (RESIDENTIAL_GDP)	0.88	0.00*
RESIDENTIAL_Real Energy Price	–0.04	0.00*
Dep Var: Δ (COMMERCIAL_Energy demand)		
Δ (COMMERCIAL_GDP)	0.62	0.00*
COMMERCIAL_Real Energy Price	–0.38	0.00*
Dep Var: Δ (TRANSPORT_Energy demand)		
Δ (TRANSPORT_GDP)	1.01	0.00*
TRANSPORT_Real Energy Price	–0.07	0.00*

* denotes significance at 95 per cent level