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Quantifying the social equity of carbon mitigation strategies

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Quantifying the social equity of carbon mitigation strategies

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Many tools that are helpful for evaluating emissions mitigation measures, such as carbon abatement cost curves, focus exclusively on cost and emissions reduction potential without quantifying the direct and indirect impacts on stakeholders. The impacts of climate change will be the most severe and immediate for billions of poor people, especially for those whose livelihoods are based on agriculture and subsistence activities and are directly dependent on weather patterns. Thus, equity and vulnerability considerations must be central to GHG emissions reduction strategies. A case study of a carbon abatement cost curve for an electricity system in two Nicaraguan rural villages is presented and is complemented with assessments based on the poverty metrics of the poverty headcount, the Gini coefficient, and the Kuznets ratios. Although these metrics are relatively easy to calculate, the study provides a general indication as to how the social impacts of mitigation strategies on the poor (whether they are in rural or urban environments, developed or developing countries) can be revealed and highlights the inequalities that are embedded in them. Further work analysing how mitigation measures affect the various more detailed poverty indices, such as the Human Development, Gender Equality, or Multidimensional Poverty indices, is needed.

Keywords: climate change mitigation; development and climate; equity; local policy; poverty alleviation; socio-economic impacts

Nombreux outils utiles à l'évaluation des mesures de mitigation des émissions, tels que les courbes de coûts de réduction du carbone, se concentrent exclusivement sur le coût et le potentiel de réduction des émissions, à l'exclusion d'une quantification des impacts directs et indirects sur les parties prenantes. Ces impacts du changement climatique seront les plus prononcés et immédiats pour des milliards de gens pauvres, en particulier ceux dont les modes de vie sont basés sur l'agriculture et les activités de subsistence directement dépendentes des tendances météorologiques. De ce fait, les questions d'équité et de vulnérabilité doivent être centrales aux stratégies de réduction des émissions des GES. Une courbe de coûts de réduction du carbone pour un système d'électrification dans deux villages ruraux au Nicaragua est présentée en tant qu'étude de cas, complémentée d'une évaluation basée sur les taux de pauvreté ('poverty headcount'), le coefficient de Gini et la courbe de Kuznets. Bien que ces mesures soient relativement faciles à calculer, l'étude fournit des indications générales sur la manière selon laquelle les impacts sociaux des stratégies de mitigation sur les pauvres (que ce soit en milieu rural ou urbain, dans des pays développés ou en développement) peuvent etre révélés et montre les inégalites y étant inscrites. Des travaux d'analyse supplémentaires sont nécessaires à l'analyse de l'effet des mesures de mitigation sur les différents indices de pauvreté plus détaillés, tels que développement humain, égalité des sexes et pauvreté multidimensionnelle.

Mots clés : mitigation du changement climatique; développement et climat; équité; politique locale; réduction de la pauvreté; impacts socio-économiques

1. Poverty, adaptation, and mitigation

A staggering proportion of the global population faces daunting challenges in order to survive. Almost a quarter of humanity survives on less than US$1.25 per day (World Bank, 2010). A similar number have

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no access to electricity, while 3 billion people lack adequate sanitation and 1 billion people have no clean drinking water (UNDP, 2010a). For many of these marginalized communities, the daily struggle for survival will be made more difficult by the environmental shocks that result from climate change (Lobell et al., 2008; Hertel and Rosch, 2010).

The World Bank (2010) estimates that 75–80% of the costs and damages caused by future climate changes will be borne by the poorest communities. Those whose daily livelihoods are intimately tied to their natural resources will also be most vulnerable to climate change (IPCC, 2007a; Hertel and Rosch, 2010; Ribot, 2010; World Bank, 2010). They will have the greatest exposure to change and the least capacity to adapt (Tol et al., 2004). Just under half of the global population currently lives in rural areas. The livelihoods of 85% of this population are dependent on agriculture (World Bank, 2008), and 70% of them live in extreme poverty (IFAD, 2010). Studies show that as mean temperatures in tropical and mid-latitudes rise, there will be a decrease in average agricultural yields, with communities in Asia and Africa affected worst (World Bank, 2010).

Poor communities in rural areas are not the only populations susceptible to climate change. The poor, the elderly, and children in urban populations are also vulnerable to climate change. For example, decreasing agricultural yields affect food prices, decreasing the welfare of the urban poor (Brown and Funk, 2008; Lobell et al., 2008). The heat waves in 2003 in Europe resulted in devastating increases in mortality, particularly among the elderly living in urban areas (Salagnac, 2007; Martiello and Giacchi, 2010). Warmer temperatures and an increased concentration of CO_2 in urban environments increase the pollen count, a primary contributor to asthma, the largest chronic disease among children (Bloomberg and Aggarwala, 2008; Kinney, 2008).

Dialogue over the connection between climate change and the poor has primarily focused on issues of equity in emissions (Baer et al., 2000) and adaptation (Smit and Pilifosova, 2003; Tol et al., 2004; Tompkins and Adger, 2004; Paavola and Adger, 2006; Ribot, 2010). Much of the adaptation literature addresses the link between climate change and poverty, framing it in terms of vulnerabilities, accounting for one's exposure, and capacity to adapt to risk. Deprivation of money, education, health care, housing, security, and social and political participation are all manifestations of poverty (Sen, 1999; UNDP, 2010b, p. 94) that can affect a person's ability to adapt to climate shocks.

There is a growing body of literature concerning the link between mitigation and poverty, which primarily focuses on the societal impacts of agriculture and forestry projects (Ribot et al., 2006; Olsen 2007; Pearson 2007; Hertel and Rosch, 2010; Phelps et al., 2010). Many of the studies that directly explore the more general relationship between mitigation and poverty merely consider clean development mechanism (CDM) projects (Lenzen et al., 2007; Olsen, 2007), while other, more general mitigation policy studies focus on environmental effectiveness and costs, with considerably less attention paid to the relationship between poverty and equity (Konidari and Mavrakis, 2007; Heinrich Blechinger and Shah, 2011).

Mitigation projects, however, can have many direct and indirect impacts on the poor, not just in the agricultural and forestry sectors (Casillas and Kammen, 2010). It is shown here, using a case study, how the relationship between mitigation and poverty can be made more explicit at local and national levels in general climate policy and planning dialogue.

2. Evaluating carbon mitigation potential and strategies

GHG mitigation focuses on politically, technically, and economically feasible emissions reduction strategies. The 2007 Fourth Annual Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) classifies the areas with the greatest mitigation potential into the following sectors: energy supply, transportation, buildings, industry, agriculture, forests and forestry, and waste management (IPCC, 2007b). A breakdown by economic sector of GHG emissions sources, as well as an estimate of the range of annual emissions reductions that may be achievable for less than $100/t$CO_2$e, is given in Table 1.

There are many options that can be targeted for mitigating GHG emissions. Some involve reducing emissions from fossil fuel-based technologies, while others involve the management of carbon sinks in the forestry and agriculture sectors. Table 2 shows, for the different sectors, the instruments and policies that – with varying levels of effectiveness – have been implemented.

The AR4 defines four main criteria that should be used to evaluate carbon mitigation instruments and policies (IPCC, 2007b, p. 751): environmental effectiveness, cost effectiveness, distributional and equity effects, and institutional feasibility. Although the reports and other discussions of the IPCC clearly highlight equity issues, they are often presented at the qualitative level, and are yet to be utilized in commonly used metrics for evaluating projects. The best example of a climate policy measure that seeks to take account of equity issues in a structured analysis is the use of multi-criteria evaluations in CDM projects (Lenzen et al., 2007).

The mitigation analysis tools commonly used by policy makers that are more quantitative in nature focus on carbon costs and abatement potentials without quantifying the impacts of the mitigation projects on poverty. The recent prevalence of carbon abatement cost curves provides a clear example. A carbon abatement cost curve typically shows the average or marginal cost of reducing emissions relative to a given baseline, through the introduction of a new technology or policy (Klepper and Peterson, 2006). The curves provide approximations of mitigation supply curves, often for national or global economies, showing the approximate cost (in $/t$CO_2$e) for various measures and the total abatement potential. In the last few years, management consulting firm McKinsey and Co. and the World Bank have begun constructing numerous carbon abatement cost curves for national economies. These studies focus on cost and carbon metrics, with little effort to quantify stakeholder impacts (Ekins et al., 2011).

A modified version of an economy-wide carbon abatement cost curve for Mexico, taken from a World Bank report (Johnson et al., 2009) is presented by way of illustration (see Figure 1). Three criteria are used to select the mitigation interventions: the interventions should result in the mitigation of over 50 million tonnes of CO_2e before 2030, have costs below $25/t$CO_2$e, and must be technically and financially feasible in the near term. The nearest the report comes to addressing equity concerns is a mention of the potential health co-benefits that may result from reducing emissions. To illustrate

TABLE 1 2004 GHG emissions and estimated mitigation costs by sector

Sector	2004 GHG emissions (% of total)	Mitigation potential for less than 100 US$/t$CO_2$e (in Gt$CO_2$e/year)
Energy supply	26	2.4–4.7
Industry	19	2.5–5.5
Forestry/forests	17	1.3–4.2
Agriculture	14	2.3–6.4
Transport	13	1.6–2.5
Buildings	8	5.3–6.7
Waste management	3	0.4–1

Source: IPCC (2007b).

TABLE 2 Potential for significant GHG mitigation by sector

Sector	Potential instruments or policies
Energy supply	Reduction of fossil fuel subsidies
	Taxes or carbon charges on fossil fuels
	Feed-in tariffs for renewable energy technologies
	Renewable energy quotas
	Generation subsidies
Industry	Provision of benchmark information
	Performance standards
	Subsidies, tax credits
	Tradable permits
	Voluntary agreements
Forestry/forests	Financial incentives (national and international) to increase forest area, to reduce deforestation, and to maintain and manage forests
	Land use regulation and enforcement
Agriculture	Financial incentives and regulations for improved land management, maintaining soil carbon content, efficient use of fertilizers and irrigation
Transport	Mandatory fuel economy, biofuel blending, and CO_2 standards for road transport
	Taxes on vehicle purchase, registration, use and motor fuels, road and parking pricing
	Influence mobility needs through land use regulations, and infrastructure planning
	Investment in attractive public transport facilities and non-motorized forms of transport
Buildings	Appliance standards and labelling
	Building codes and certification
	Demand-side management programmes
	Public sector leadership programmes, including procurement
	Incentives for energy service companies (ESCOs)
Waste management	Financial incentives for improved waste and wastewater management
	Renewable energy incentives or obligations
	Waste management regulations

Note: The policies and measures listed are those that have been found to be environmentally effective in national-level implementations.
Source: IPCC (2007b).

the inequalities embedded in the mitigation analysis, a number of the interventions have been highlighted to contrast the different social impacts that could result. Each box in the curve represents a different mitigation measure, ordered from the cheapest to the most expensive. The *x*-axis shows an estimate of the total abatement potential for each measure over a 22-year time frame, while the *y*-axis represents the average cost to society, relative to a business-as-usual scenario. Measures that fall below the *x*-axis represent net savings. The light grey boxes represent measures that could have direct co-benefits to the poorest populations, through monetary savings, employment, or the local reduction of air pollution. The grey and white striped boxes represent measures that would primarily provide benefits to owners of industry, as well as the skilled labour force.

Coincidentally, the cheapest carbon mitigation option in the supply curve is optimization of the bus system, which would probably benefit many of the poorest urban populations. Improved public

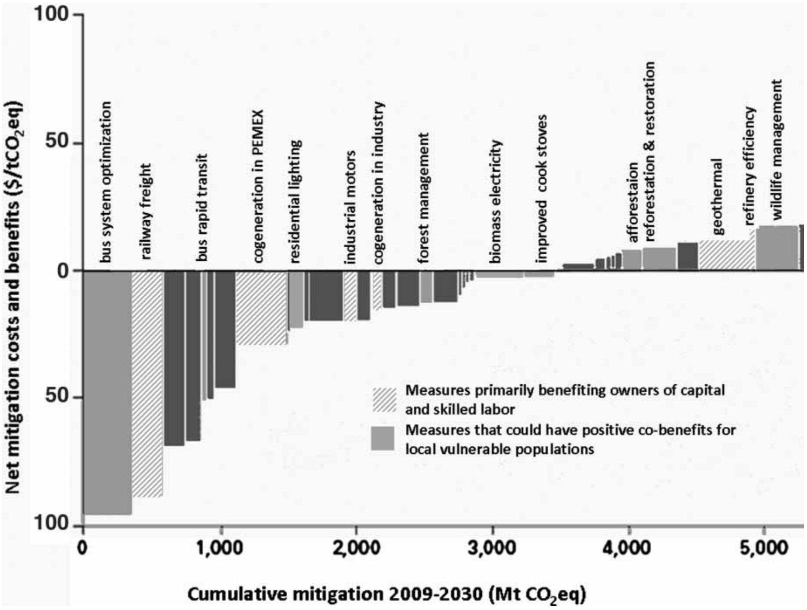

FIGURE 1 Carbon abatement curve adapted from Johnson et al. (2009).
Note: The width of each box represents the cumulative mitigation potential ($MtCO_2eq$), and the height represents the net mitigation costs, relative to a business-as-usual baseline. Measures below the *x*-axis represent a net savings. Only a portion of the interventions are labeled, in order to highlight the differential social impacts between them. The interventions labeled with light grey boxes could provide direct co-benefits to poor urban and poor rural populations, through increased employment, savings, and improved air quality. The grey and white boxes represent measures that would likely benefit owners of industry and support job creation for skilled labor forces. Although not all the measures are highlighted, it is estimated that 40% of all mitigation measures in the curve could have positive co-benefits for poor populations, representing slightly more than 2000 $MtCO_2eq$.

transportation in urban mega-cities can disproportionately benefit the poorest sectors, decreasing transportation times and reducing air pollution (INE, 2008).

Forestry and natural resource management is another sector that will have significant impacts on vulnerable communities. Almost 65% of global mitigation potential (up to $100/$tCO_2e$) is located in the tropics, and approximately 50% of this potential could be met through the reduction of deforestation (IPCC, 2007c, p. 14). However, the manner in which deforestation projects are structured is critical in determining whether or not they will improve the livelihood of local stakeholders (Agrawal et al., 2008; Phelps et al., 2010). Although Mexico already has over a decade of experience with forest management being used for carbon mitigation, there is conflicting evidence regarding its benefits to rural stakeholders (Brown and Corbera, 2003; Nelson and de Jong, 2003). Marginalized communities who primarily live off the land could suffer if forests and other resources are only valued in terms of monetary or carbon metrics, especially when projects alter relationships of traditional resource access (Ribot and Peluso, 2003; Corbera et al., 2007; Phelps et al., 2010).

It is important to understand, beyond the implementation of adaptation measures, how the current challenges of alleviating poverty and responding to climate change can be addressed. This requires understanding the links between mitigation measures and the welfare of marginalized communities.

Mitigation strategies necessarily involve changes to environments and infrastructure and might also induce structural changes to economies. This will create winners and losers and may provide opportunities for reducing the vulnerabilities of marginalized populations.

Although issues of equity continue to be pervasive in the climate discussions regarding abatement and emissions rights, they are noticeably absent from the mainstream analysis of mitigation. Carbon abatement cost curves have become ubiquitous because they have an intuitive logic and are easy to interpret, thus making them attractive to policy planners. The very fact that carbon abatement cost curves are presented without highlighting stakeholder impacts creates the risk of implementing climate programmes that could widen socio-economic inequalities, thus exacerbating any extant conditions of climate vulnerability. By attempting to quantify, or at the very least highlight, the potential poverty alleviation opportunities that coincide with carbon mitigation interventions, carbon abatement cost curves can keep issues of equity and poverty within the discussions of climate mitigation, which would be a first step towards integrating them into planning and implementation.

3. Poverty impacts of carbon mitigation in the rural electricity sector: a case study

In this section, socio-economic data are used to demonstrate how they can be used to complement carbon abatement cost curves with measures of poverty and equity. The case study is at the community level and illustrates how socio-economic data and an understanding of local impacts can be incorporated into policy decisions (which are often made at the national level). The following analysis is based on interventions made to an electricity system that serves two small rural villages in Nicaragua (Casillas and Kammen, 2011). Although the poverty and equity analysis was in fact developed after their implementation (rather than in the planning stages), it provides empirical support for a methodology that can be integrated into the planning process.

Nicaragua has one of the lowest electrification rates in Central America, and its generation portfolio is primarily composed of petroleum-based fuels, which are used in thermal power plants (Mostert, 2007). The government is currently embarking upon an ambitious project that will vastly increase electricity access throughout the country, and shift the generation portfolio from fossil fuels to renewable energy sources. As will be shown, community-level case studies can complement national implementation plans by providing insight into the micro-level equity impacts of policies.

The villages in the study are located on the Atlantic coast of Nicaragua. Communities on the coast remain some of the most impoverished in Central America as measured using the metrics of monetary earnings and lack of access to public goods such as education, health care, clean water and electricity (Hegg, 2005; UNDP, 2005; Nicaragua, 2006). The communities on the Atlantic coast have characteristics that are typical of the many vulnerable, rural communities throughout the global south. The coastal villagers are both fishers and farmers, and depend on marine and terrestrial ecosystems for their livelihoods; they therefore live at the crossroads of complex environmental, social, and economic systems (Christie, 2000; González, 2011).

3.1. Village carbon abatement cost curve

The case study takes place in two neighbouring villages with populations of approximately 800 and 350 inhabitants. The monetary incomes in both communities mainly come from fishing, and the majority of households participate in subsistence-level agriculture. The two villages are connected to a stand-alone electricity grid (consisting of a diesel generator run by the national electric company), which provides 12 hours of electricity service. In 2009, nearly 70% of the electric load was consumed by 172 residential houses, and 25% of the load went to public lighting.

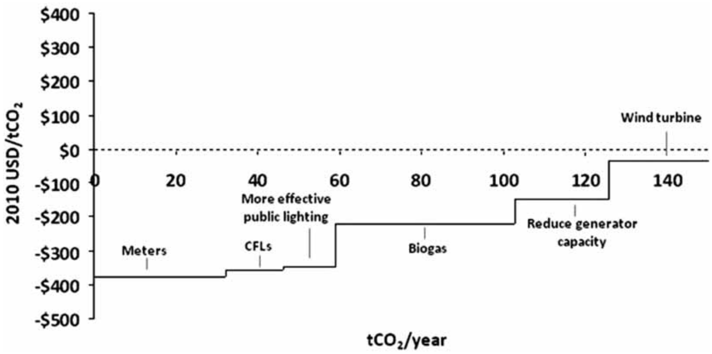

FIGURE 2 Carbon abatement cost curve: Abatement cost is with respect to a baseline diesel carbon price of 397 $/tCO_2$. Abatement potential is due to the reduction of diesel use, relative to each previous measure. Multiplying abatement potential and abatement cost gives total annual costs (negative cost = savings) relative to the baseline, assuming the previous measure was implemented.

During the summer of 2009, conventional electricity meters were installed in order to modernize the previous collection system (which was based on a fixed charge reflecting the power rating and number of appliances owned by each household). An energy efficiency campaign was then carried out in which each household was given the opportunity to receive two 13 W compact fluorescent lights (CFLs) in exchange for two incandescent lights. The installation of the meters and the CFLs resulted in a 28 and 17% reduction, respectively, in the electricity load. A carbon abatement cost curve was constructed, based on the estimated costs of the interventions and the carbon abatement that resulted from the reduction in diesel consumption (Casillas and Kammen, 2010). Costs and impacts from a number of other supply and demand side measures were also estimated in order to create a more complete curve depicting the carbon mitigation costs that could result from interventions to the electric system (Figure 2).

3.2. Incorporating poverty and equity metrics

Several poverty metrics were calculated in order to quantify the impacts of the carbon mitigation activities on poverty and equity. Poverty headcount ratio, income and energy Gini coefficients, and Kuznets ratios were computed for each of the interventions in the carbon abatement cost curve. The estimated impact of each intervention was determined using income data from household surveys as well as residential electricity bills. The poverty metrics were calculated for a random sample of 69 households from one of the villages (which had 121 households connected to the grid). The suite of mitigation efforts included those that were actually implemented (i.e. meter and CFL installation) as well as estimates of additional interventions. The approach thus demonstrates the feasibility of estimating potential impacts of mitigation measures at the planning stages.

The metrics used in the study were chosen due to the availability of data. Both the recent UN Human Development Report (UNDP, 2010b) and the Rural Poverty Report (IFAD, 2010) provide summaries of a number of more comprehensive metrics for assessing the various aspects of poverty. Some of these metrics include aggregated indices such as the Human Development Index, the Gender Equality Index, and the Multidimensional Poverty Index. Although these measures incorporate more diverse aspects of poverty, they require more comprehensive data sets than were available in the present study. A variety of poverty measures are listed in Table 3. To determine the impacts of the mitigation measures on absolute poverty, changes to income were estimated following each intervention.

TABLE 3 Various metrics for measuring aspects of human welfare

Metric name	What it measures
Poverty headcount ratio[a]	Ratio of population below a poverty line
Gini coefficient[a]	Level of income/consumption inequality
Energy Gini[a]	Level of energy consumption inequality in kWh
Kuznet ratio[a]	Level of inequality between the wealthiest and poorest
Human Development Index	Index based on measures of life expectancy, income, and education (level and years of schooling)
Gender Inequality Index	Index comprising reproductive health (childhood mortality rate and adolescent fertility rate), empowerment (gender equality in education and parliamentary seats), and labour (gender participation in the labour force)
Multidimensional Poverty Index	Index comprising measures of health (childhood mortality and nutrition), education, depth and intensity of income poverty, and standard of living (cooking fuel, toilet, water, electricity, floor, assets)

Note: Mitigation measures could be evaluated based on its estimated impact on the various poverty or inequality measures.
[a]Used in the analysis in this paper.

The poverty headcount ratio p is an absolute poverty measure that reveals the portion of a population below a certain income, or consumption cutoff, defined as

$$p = \frac{q}{n}$$

where n is the total population size and q is the number of people below the given cutoff. Although the headcount ratio is a simple measure, it provides an indication as to whether a particular intervention significantly impacts the income or consumption potential of the poor. Accounting for purchasing power parity among countries, the World Bank currently uses a value of \$1.25/day as the cutoff point for poverty (Ravallion et al., 2009). It is important to note that using this value for the villages is not very meaningful in assessing the consumption aspect of poverty because of the higher cost of basic foods for these remote villages and the subsistence livelihoods of many of the families living there. However, the value does provide insight into the potential that these families have for paying for goods and services, in comparison to other regions of the country.

Gini coefficients and Kuznets ratios were used in order to measure the impacts of the mitigation measures on inequality. The Gini coefficient is a commonly used measure of income inequality within a population (Ray, 1998). A Gini coefficient of zero denotes a community with perfect income equality, and a coefficient of one means that all of the income is held by a single individual. Separate Gini coefficients were calculated from the income data as well as the electricity consumption data from household bills. The consumption Gini coefficient indicates whether or not the mitigation intervention impacts the distribution of wealth, while the energy Gini coefficient indicates the distribution of electricity access (Jacobson et al., 2005).

Kuznets ratios give the ratio of the share of income held by the poorest 20% to the income share held by the richest 20%, as a measure of inequality between the tails of the income spectrum. Table 4 shows the resultant change to the poverty metrics following the actual or estimated implementation of each carbon mitigation measure.

The poverty headcount ratio is most affected by the meter and CFL installation and biogas generation. Prior to meter installation, many households left their appliances and lighting on, even when they were not using them. Due to the fixed tariff, they knew they would be charged the same

TABLE 4 Change to poverty and inequality measures

	Mitigation measure	Poverty headcount	20/20 Kuznets ratio	Income share of bottom 20%	Income share of top 20%	Gini coefficient	Energy Gini coefficient
	Baseline	0.53	18.39	3.07	56.46	0.51	0.45
1	Meter installation	0.52	17.74	3.18	56.37	0.51	0.43
2	CFL installation	0.50	18.09	3.13	56.53	0.51	0.48
3	More effective street lights	0.50	17.22	3.27	56.28	0.51	0.45
4	Biogas	0.48	11.23	4.84	54.33	0.47	0.45
5	Reduce diesel plant capacity	0.48	11.23	4.84	54.33	0.47	0.45
6	Wind turbine (class 2)	0.48	11.23	4.84	54.33	0.47	0.45

Note: Figures were calculated following the implementation of various carbon mitigation measures.
Source: Authors own calculations, based on earnings and electricity consumption data from 69 of the 121 households that have electricity in one of the two of a Nicaraguan villages.

whether or not they turned their appliances off. With the implementation of metering, they began to use their appliances only at times when they valued the energy service, which for many households resulted in bills below the fixed tariff. The improved efficiency of the CFL lights resulted in additional monetary savings for most households, without a decrease in illumination. The poverty headcount ratio could have been decreased even further except for the fact that there was a regressive, two-part tariff system operating in the community, in which the poorest clients (who consumed less than 15 kWh/month) paid a fixed rate. Although the consumption of this group also fell, they received no monetary savings.

In this case study, demand changes were observed. However, at the planning stage, estimating impacts based on demand elasticities can be unreliable. This strengthens the need for increased project implementation capacity and documentation in order to have sufficient empirical evidence to support assumptions. This effort could be facilitated by the multinational development community adopting reporting requirements for energy access data across socio-economic groups, as are often implemented in the case of income to build Gini curves (Jacobson et al., 2005).

In order to demonstrate the potential poverty and equity benefits that may be derived from creating a local diesel substitute, consider the example of the production of biogas from the anaerobic digestion of animal waste. Suppose that the operation of the plant could be carried out by four workers earning a yearly salary of $1000 and that the animal residues used for anaerobic digestion could be purchased from a cooperative of 16 farmers. The electric utility could then purchase the biogas at its avoided fuel costs of 1.06 $/litre. Of this payment, 50% could be passed on to the cooperative for the purchase of the animal waste, which would result in an annual earning of $542 per farmer. The 20 beneficiaries could be chosen from among the poorest households in the community. The reduction in poverty and inequality that could result from the estimated implementation of the biogas system is seen in the relative change between measure 3 and measure 4 as depicted in Table 4.

In contrast to the local benefits arising from biogas generation, the installation of a wind turbine does not have any impacts on the chosen poverty metrics for the community. Whereas the majority of the lifetime costs for generation from an internal combustion engine are contained in the fuel

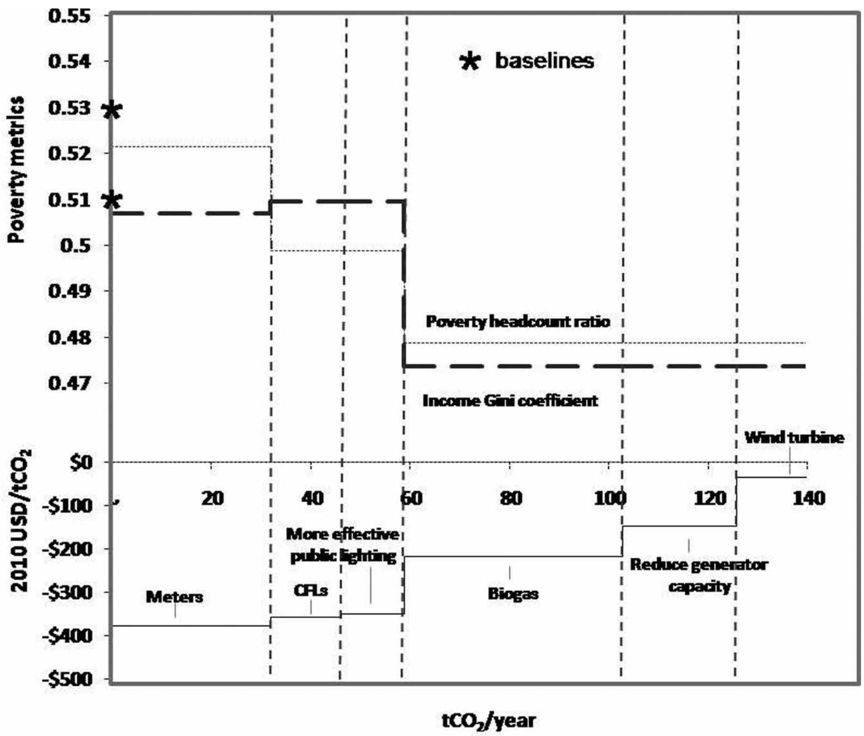

FIGURE 3 Carbon abatement cost curve with poverty metrics: Carbon abatement cost curve for diesel microgrid in rural Nicaraguan community (bottom), and the resultant change to the Gini coefficient and poverty headcount ratio for one of the rural villages (top). The Gini coefficient and poverty headcount ratio are derived from earnings and electricity consumption data from 57% of the houses having electricity service in one of the rural villages.

costs (which can be captured by communities through local fuel production), the bulk of the lifetime costs for wind or solar generation are contained in the capital cost of imported technologies.

It is worth noting that the energy Gini coefficient increases (i.e. consumption becomes more unequal) with installation of the CFLs. This is most probably due to the fact that with the drop in demand that results from increased lighting efficiency, household consumption becomes dominated by refrigeration in wealthier households, thereby increasing consumption inequality. Thus, one must take care in interpreting changes in equality metrics in the case of energy efficiency. Energy services consumed (e.g. lighting or cooling) are the appropriate measure of consumption, because energy service consumption can increase while kWh consumption falls.

Figure 3 shows a plot of the change in poverty headcount ratios and income Gini coefficients, matched with the carbon abatement cost curve. The plot demonstrates one possibility for complementing the graphical simplicity of the carbon abatement cost curve with the resulting poverty and equity impacts for a particular community.

4. Policy implications and areas for further study

Although the case study was limited to the electricity sector in a rural village, the methodology can be generalized across scales to the national level, and across most mitigation instruments and policies.

It is important to standardize and mainstream a group of poverty and inequality metrics in order to create a common dialogue regarding poverty and equity impacts for planned and extant mitigation projects. The poverty and inequality measures used in this article need to be augmented to capture the full impact of many mitigation measures. For example, changes to public transportation may not simply reduce monetary expenditures, but could also reduce opportunity costs through decreased commute times, drastically reduce air pollution, and improve health. Interventions, such as improved cooking stoves, will predominantly impact the health of women and children, who spend more time in smoke-filled kitchens than men (Smith and Haigler, 2008). More comprehensive indices such as the Human Development Index, Multidimensional Poverty Index, and Gender Inequality Index are likely to be appropriate for quantifying many of the impacts on vulnerable populations.

Implementing this methodology at the national level will necessarily be more complicated. Consider the many mitigation options in the modified carbon abatement cost curve for Mexico, presented in Figure 1. However, although it will be challenging, it is by no means impossible to estimate the impacts at the national scale of forest management projects and residential lighting. Empirical evidence from community-level interventions will be crucial for reliably estimating poverty and equity impacts and scaling them to the national level. For example, the results from the village case study here can be applied to all of the diesel microgrids in Nicaragua in order to estimate economic and distributional impacts of lighting efficiency campaigns.

It remains to be seen how various nations will prioritize issues of equity. The IPCC AR4 identifies distributional and equity effects as one of four criteria for assessing mitigation measures, but it is not as common as the criteria of environmental effectiveness, cost effectiveness, and institutional feasibility. The criteria used to prioritize mitigation choices will need to be compatible with national development strategies, which are unique to each country, especially when there are limited funds available and economic growth is a priority. The benefits of mitigation criteria will also vary between countries. In industrialized countries, inequality may be impacted more by policies affecting urban populations, whereas the impacts of agriculture and forestry policies will be more important in countries that still have significant rural populations.

Multicriteria approaches set up an appropriate framework for carefully weighing the costs and benefits of mitigation options (Konidari and Mavrakis, 2007). However, unless a pro-poor approach is taken, the voices of the most vulnerable stakeholders may be absent. Complementing popular planning tools such as carbon abatement cost curves with poverty and equity metrics will increase the transparency of discussions and decisions to community stakeholders.

5. Conclusions

GHG mitigation and aspects of community adaptation have been central topics of discussion and analysis with respect to climate change. However, many of the quantitative tools developed for policy makers have neglected the important connections between carbon mitigation and poverty. The impacts of climate change will be most severe for the billions of poor living in equatorial regions, whose livelihoods are based on agriculture and other subsistence activities, and who are dependent on rainfall and other weather patterns. However, vulnerable populations everywhere, whether in rural or urban environments, developed or developing countries, are susceptible to climate shocks.

The embedded inequalities of many carbon mitigation interventions are rarely addressed in a rigorous manner. In particular, carbon abatement cost curves create a policy framework in which cost and carbon reduction potential are the primary metrics, rather than who will be the primary beneficiaries from the interventions. Carbon mitigation strategies can have vastly different local impacts on various aspects of poverty, such as income, jobs, or energy and resource access. Even though some mitigation measures have the cheapest $/t$CO_2$e, they may have few co-benefits for the poorest stakeholders, many of whom will be most vulnerable to climate shocks. Measures with local co-benefits should be prioritized. Simple metrics such as the poverty headcount ratio, Gini coefficient, or Kuznets ratio can help illuminate the social impacts of carbon abatement interventions, highlighting how the poorest will be impacted by specific mitigation decisions.

In the present case study of two rural Nicaraguan communities, a carbon mitigation cost curve for their electricity systems has been presented, together with the relative poverty impacts of each carbon mitigation measure. Energy efficiency interventions resulted in a decrease in energy consumption without a loss of utility and provided savings to the poorest consumers, which increased their spending potential and decreased economic poverty. In addition, renewable energy supply measures such as biomass-based generation, which involve local labour and resources, can have greater local benefits than wind and solar, for which the lifetime costs are tied up in the capital costs and are captured by industry.

There are an increasing number of studies on the local impact of carbon mitigation policies, primarily in the forestry and agriculture sectors, and CDM projects. However, there is a lack of methodologies that tie the national-level planning tools (such as carbon abatement cost curves) to stakeholder impacts at the sub-national level. The methodology presented here provides an example of one that can be used to integrate empirical evidence of the impact of mitigation policies back into the planning process.

Poverty metrics such as poverty headcount ratio, Gini coefficient, or Kuznets ratios are fairly easy to calculate with the available data, but provide only limited insight into the diverse impacts that mitigation measures may have on local vulnerabilities and deprivations. As the research here demonstrates, poverty impacts can complement the simple graphical tools, such as carbon abatement cost curves, that are commonly used by policy makers. Thus, there needs to be a consolidated effort in the research and policy arena to analyse how mitigation measures affect the various more detailed poverty indices, such as the Human Development, Gender Equality, or Multidimensional Poverty indices.

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