Broadening the Appeal of Marginal Abatement Cost Curves: Capturing Both Carbon Mitigation and Development Benefits of Clean Energy Technologies

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ABSTRACT

Low emission development strategies (LEDS) articulate policies and implementation plans that enable countries to advance sustainable, climate-resilient development and private sector growth while significantly reducing the greenhouse gas (GHG) emissions traditionally associated with economic growth. In creating a LEDS, policy makers often have access to information on abatement potential and costs for clean energy technologies, but there is a scarcity of economy-wide approaches for evaluating and presenting information on other dimensions of importance to development, such as human welfare, poverty alleviation, and energy security. To address this shortcoming, this paper proposes a new tool for communicating development benefits to policy makers as part of a LEDS process. The purpose of this tool is two-fold:

1. Communicate development benefits associated with each clean energy-related intervention
2. Facilitate decision-making on which combination of interventions best contributes to development goals

To pilot this tool, the authors created a visual using data on development impacts identified through the Technology Needs Assessment (TNA) project in Montenegro. The visual will then be revised to reflect new data established through the TNA that provides information on cost, GHG mitigation, as well as the range and magnitude of development impacts.

1. INTRODUCTION

The Cancun agreements describe low emission development strategies (LEDS) as “indispensible to sustainable development” (1).[1] Such strategies outline pathways for countries to advance sustainable, climate-resilient development and private sector growth while significantly reducing the greenhouse gas (GHG) emissions traditionally associated with economic growth. Guided by each country’s development goals, a LEDS articulates economy-wide development scenarios, and the policies, programs, financing, and implementation plans necessary to achieve those scenarios. Unlike with traditional GHG mitigation programs, actions considered for a LEDS cannot be at the expense of achieving a country’s development priorities, such as economic growth, energy security, poverty alleviation, and human welfare.

Constructing a LEDS requires a tool that enables governments to evaluate and prioritize mitigation measures and corresponding policies for implementation of these measures across an economy and clearly explain the process used to make this determination. Because countries’ development priorities are the drivers behind LEDS, optimization tools used for LEDS should incorporate development benefits to reflect this priority.

[1] The terms low *carbon* and low *emission* development strategies are used interchangeably in literature. Low carbon development strategies is used in the Cancun Agreements (1/CP.16.6 and 65), but several studies and programs use the term low emissions development strategies as it better reflects the emissions of different GHGs as defined in Annex A of the Kyoto Protocol.

Yet leading tools used by practitioners do not always adequately capture or communicate the development impacts of proposed actions. To address this shortcoming, the authors reviewed existing approaches to capturing and communicating development benefits of climate action and proposed a new tool for communicating development benefits to policy makers as part of a LEDS process. The purpose of this tool is two-fold:

1. Communicate development benefits associated with each LEDS-related intervention
2. Facilitate decision-making on which combination of interventions best contributes to development goals

2. EXISTING TOOLS TO ANALYZE AND PRESENT CLIMATE AND DEVELOPMENT BENEFITS

A leading tool to prioritize GHG mitigation options is a Marginal Abatement Cost Curve (MACC or MAC curve), which is a variable width bar graph with GHG mitigation options arranged from least to highest cost per unit of reduced carbon. The y-axis represents the marginal cost of carbon abatement using the listed option and the x-axis represents the total abatement potential for that option. MAC curves have been valued for their clear presentation and cost-based prioritization of abatement options, but criticized for underrepresentation of costs and barriers associated with implementation (2) and for not being designed to identify and present benefits of technology implementation beyond GHG mitigation.

MAC curves are also dependent on a variety of static assumptions about cost and performance that may vary widely across the region of interest, ignore intra- and inter-sectoral interactions, and may not capture national and international dynamics that impact technology costs. Nevertheless, MAC curves can be useful tools for engaging policy makers in discussions of the technology options that could offer substantial abatement opportunities and in the exploration of associated policy actions that could be taken to exploit those opportunities.

To identify development benefits, analysts must draw on a series of other tools, some of which are computationally intensive. One example is the relationship between GHG mitigation and impacts to public health through improved air quality. The relationships among emissions from energy use and industrial processes, pollutant concentrations, health outcomes, and consequent losses in economic productivity can help estimate health-based development benefits associated with climate action. Even with this well-studied example, there are challenges to adequately representing the full spectrum of impact across a population; this is most apparent when one considers the value assigned to those outside the formal economy, which includes many women and young children.

Macroeconomic models can also be used to assess economic development impacts of low carbon actions. These models have been developed in a number of countries, and while useful for assessing macroeconomic indicators such as Gross Domestic Product (GDP) and employment, they do not capture many micro-level indicators associated with gender, education, etc. Data intensity and computational requirements may also be barriers to the use of macroeconomic models in some countries.

Another example of a tool that assesses GHG mitigation (and adaptation) options in terms of climate and development benefits is that of a Technology Needs Assessment (TNA) (3).[2] In a TNA, country stakeholders revisit the country's sustainable development priorities, which are subsequently used as criteria for identifying strategic sectors for climate and development, and prioritizing mitigation and adaptation options within these sectors. The TNA process is highly participatory and suggests using a detailed multi-criteria decision analysis (including sensitivity analysis), which supports mobilizing stakeholders' knowledge and taking robust decisions.

The choice in tools for identifying development benefits depends on whether the development objective is primarily anti-poverty (or improved well-being) or economic growth. Many of the growth-focused benefits can be evaluated as part of a macro-economic modeling effort and quantified in economic indicator terms. In contrast, anti-poverty benefits may have more complex causal chains and have less accepted methodologies for impact assessment. These realities preclude straightforward and easily calculable relationships between climate action and development impacts. In order to deal with that complexity, the TNA process invites stakeholders to score climate options based on how well these contribute to development benefits. This

[2] The TNA concept was included in the Decision on 'Development and Transfer of Technologies' at COP7 (2001) to help developing countries identify technology needs for mitigation and adaptation. An updated TNA methodology was endorsed by the UNFCCC Expert Group on Technology Transfer at its 6th meeting on *Development and Transfer of Technologies* (Bonn, Germany, 19-20 November 2010). Currently, 36 developing countries conduct TNAs under the GEF/UNEP TNA project (http://tech-action.org).

relative scoring method reduces the need for quantification.

3. NEW TOOL TO COMMUNICATE CONTRIBUTIONS OF LEDS INITIATIVES TO DEVELOPMENT GOALS

To meet the objectives outlined above—communicating development benefits and facilitating decision-making on interventions for LEDS—the authors propose the visual in Figure 1.[3] This visual purposefully includes the MAC curve, recognizing its value and prevalence in supporting LEDS. This visual rotates the MAC curve on its side with the lowest cost technology option at the top of the page. To the right of the rotated MAC curve are the names of the technologies represented in the curve and associated development benefits differentiated by type. The impact of the technology on the benefit type is depicted as highly positive, positive, neutral, or negative. This designation can be made based on qualitative or quantitative evaluation, as allowed by available data.

The development impacts presented in the sample graphic are broadly categorized into social, economic, and environmental impacts. The specific benefits chosen for this graphic are based on targets established by programs such as the Millennium Development Goals and common development goals targeted by non-climate programs, and reflect both anti-poverty and economic growth-based development objectives. The last columns relate to ease of implementation of each option and may capture some of the non-technical and non-cost barriers to implementation that are not captured in the MAC curve. To better inform decisions, a recording can be added with a rationalization of why a score was given and whether there have been disagreements among stakeholders in the process.

By compiling multiple criteria into one simplified visual, this tool is expected to reduce complexity inherent to comparing technologies across multiple sectors.

The suggested technologies and benefits are not meant to be exhaustive nor rigid. A visual for a given country will include benefits that reflect that country's priorities and the information available to assess the impacts.

Many of the cautions given for use of MAC curves also apply to the approach of this graphic. Potential carbon emission reductions assume full penetration at a single point in time and technologies are analyzed in isolation.

[3] This figure is illustrative and not representative of actual research.

This simplification may end up overstating the potential development benefits if less than full penetration of a technology would result in uneven application across socio-economic strata. The fully realized impacts will also depend on the paths chosen to exploit low-emission opportunities, including policy design. This visual, as is the case with MAC curves, is meant to be a communication tool to facilitate meaningful stakeholder dialogue on the interplay between climate action and development impacts. Likely outcomes would need to be further analyzed in the context of planned policy, enforcement, and changing international market dynamics.

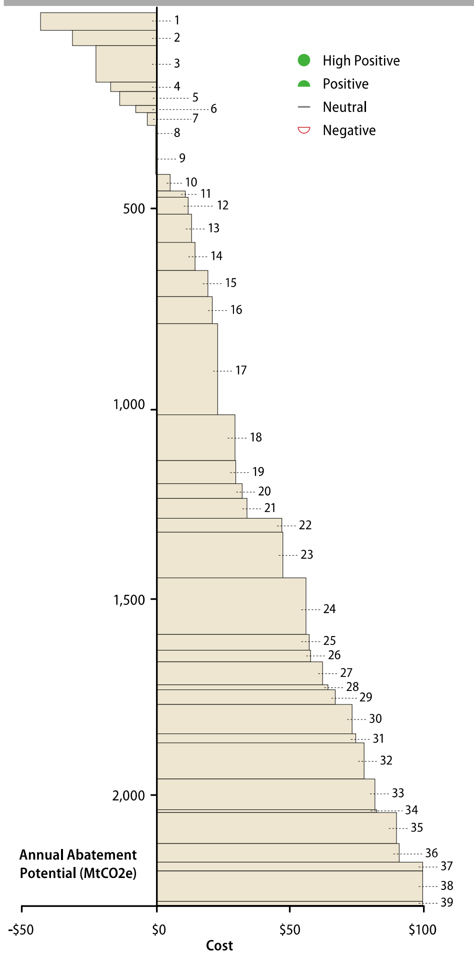
4. PILOTING THE VISUAL

The information needed for this new communication tool can build from existing LEDS, supplementing with information on development benefits and ease of implementation in order to better inform decisions on LEDS scenarios. As explained above, one program that does consider difficult-to-quantify development benefits is the Technology Needs Assessment (TNA) approach. Once priority subsectors are identified for a TNA, potential GHG emission reductions and impact on development goals (social, economic, and environmental) are evaluated for a variety of technologies in that subsector. TNAssess, a spreadsheet-based tool to help compile and analyze this information, allows stakeholders to identify, evaluate, and prioritize technologies based on user-defined criteria. Capital costs and operating and maintenance (O&M) costs are included to identify whether a technology is appropriate for a given country.

A TNA in Montenegro serves as the basis for the first pilot use of the development impact visual presented in Figure 1.[4] As a first step, the TNA identified energy, transport, and aluminum production as priority sectors for achieving Montenegro's development objectives and contributing to GHG mitigation goals. This was done in a participatory workshop (7-8 November 2011) with a broad range of stakeholders from different sectors (energy, agriculture, forestry, transport, aluminum), representing private and public sector institutes. The stakeholders identified potential technologies within these sectors, and Montenegrin consultants compiled "technology sheets", based on stakeholder input. Overall, 25 mitigation technologies were analyzed. These technology sheets describe GHG mitigation potential, associated costs, and environmental, economic, and social benefits expected from each technology's implementation. The visual

[4] The TNA in Montenegro is conducted during 2011-2012 with support from the Netherlands' Government.

Fig. 1. Proposed visual to simultaneously communicate GHG mitigation potential and development benefits of technology options



Technologies	Social Impacts					Economic Impacts				Environmental Impacts		Ease of Implementation			
	Health	Education	Gender	Rural Development	Energy Access	GDP	Employment	Local Industry	Trade	Water	Biodiversity	Alignment with Political Priorities	Variety and Number of Stakeholders Involved	Proximity to Current Regulation	Awareness and Acceptance
1. Lighting	Neutral	Neutral	Neutral	High Positive	Negative	Negative	Positive	High Positive	Negative	Neutral	Negative	Neutral	High Positive	Positive	Positive
2. Smart Grid – Automated Residential Systems	Positive	Negative	High Positive	Positive	Neutral	Neutral	High Positive	Neutral	Neutral	Positive	Positive	Neutral	Negative	High Positive	Negative
3. Smart Grid - AMI with Visual Display	High Positive	High Positive	Positive	Neutral	High Positive	Positive	Positive	High Positive	High Positive	Neutral	Neutral	Negative	Negative	Neutral	High Positive
4. Building Management Systems	High Positive	Neutral	Positive	Positive	High Positive	Positive	Positive	High Positive	Positive	High Positive	Negative	Positive	Positive	High Positive	Negative
5. Hybrid Vehicles	Neutral	Neutral	Neutral	Positive	Neutral	Positive	Negative	Positive	High Positive	High Positive	Positive	High Positive	Neutral	High Positive	High Positive
6. Geothermal	Neutral	Negative	Positive	Neutral	Positive	Positive	Neutral	Positive	High Positive	Positive	Positive	Neutral	Positive	Negative	Positive
7. Landfill Gas Power Generation	Negative	High Positive	Negative	High Positive	High Positive	Negative	Negative	Positive	Positive	Positive	Negative	Positive	Positive	Negative	Negative
8. Wind (low-cost)	Neutral	High Positive	Positive	Negative	Positive	High Positive	Negative	Neutral	Neutral	High Positive	Neutral	Neutral	Positive	High Positive	High Positive
9. Industrial Improvements (retrofits, new builds)	Negative	Positive	High Positive	Negative	Neutral	Negative	High Positive	High Positive	Negative	Negative	High Positive	High Positive	Neutral	Positive	Neutral
10. Soil Sequestration (mid-cost)	Neutral	High Positive	Neutral	Positive	Neutral	Negative	Neutral	Neutral	Positive	Positive	High Positive	Neutral	Negative	Negative	High Positive
11. Soil Sequestration (high-cost)	Neutral	Neutral	Neutral	Neutral	High Positive	Negative	Neutral	Neutral	Neutral	Positive	Neutral	High Positive	Negative	Neutral	Neutral
12. Crop Rotations	Positive	Positive	Negative	Neutral	High Positive	High Positive	Positive	High Positive	Neutral	Negative	Neutral	Neutral	Negative	Negative	Negative
13. Afforestation (low-cost)	Neutral	Positive	High Positive	Negative	Negative	High Positive	Positive	Positive	High Positive	Neutral	High Positive	High Positive	Neutral	Neutral	Negative
14. Forest Management (mid-cost)	Neutral	Neutral	High Positive	Negative	Positive	High Positive	Negative	Negative	High Positive	Neutral	Positive	High Positive	High Positive	High Positive	Neutral
15. Efficiency-Commercial Retrofits	Neutral	Positive	High Positive	High Positive	High Positive	Negative	Neutral	Positive	Positive	Positive	Negative	Negative	High Positive	High Positive	Positive
16. Efficiency-Residential Retrofits	Positive	High Positive	Positive	Negative	Neutral	Negative	Negative	High Positive	Negative	Positive	Negative	Negative	Neutral	Neutral	Neutral
17. Wind (high-cost)	Neutral	Positive	Negative	Neutral	High Positive	High Positive	Negative	High Positive	Negative	Negative	Positive	Negative	Negative	Positive	Negative
18. Afforestation (mid-cost)	Neutral	Positive	Neutral	High Positive	Negative	Negative	High Positive	High Positive	Neutral	Negative	Neutral	Neutral	Positive	High Positive	High Positive
19. Forest Management (high-cost)	Negative	Positive	High Positive	Negative	Negative	Positive	Neutral	High Positive	High Positive	Positive	Negative	Neutral	Neutral	Neutral	Negative
20. Plug-in Vehicles	High Positive	High Positive	High Positive	Neutral	High Positive	High Positive	Negative	Positive	High Positive	Negative	High Positive	Neutral	Negative	Positive	Positive
21. Ethanol-fueled Vehicles	Positive	Neutral	High Positive	High Positive	Neutral	Positive	Negative	Negative	Neutral	Neutral	Neutral	Positive	Neutral	Neutral	Positive
22. Solar PV (utility scale)	Neutral	High Positive	Neutral	Neutral	Negative	Negative	Negative	High Positive	Negative	Negative	Neutral	Negative	Neutral	Positive	High Positive
23. Nuclear	High Positive	Negative	Negative	Negative	Neutral	High Positive	Positive	Positive	Negative	Neutral	High Positive	High Positive	Neutral	Neutral	Positive
24. CCS (new build, post-combustion coal)	Positive	Negative	High Positive	Negative	Neutral	Positive	High Positive	High Positive	Negative	Positive	Neutral	Positive	Neutral	Negative	High Positive
25. Efficiency-Residential New Builds	Negative	High Positive	High Positive	Negative	Positive	Positive	Neutral	Positive	High Positive	High Positive	High Positive	Positive	Positive	Positive	High Positive
26. Landfill Projects (high-cost)	Neutral	Negative	High Positive	Neutral	Negative	High Positive	Neutral	High Positive	Positive	Positive	High Positive	High Positive	High Positive	Neutral	Neutral
27. Biomass	Positive	Positive	Negative	High Positive	Negative	High Positive	Positive	High Positive	Negative	Positive	Negative	Positive	High Positive	Positive	Positive
28. Gas Industry Projects	Neutral	Positive	High Positive	Negative	Positive	High Positive	Positive	Neutral	Negative	Neutral	Positive	Negative	Negative	Positive	Negative
29. Electric Vehicles	Neutral	Positive	High Positive	Neutral	Positive	Negative	High Positive	Negative	Negative	Positive	Neutral	Neutral	Positive	Positive	Positive
30. CCS (retrofit, post-combustion coal)	Negative	Positive	High Positive	Negative	Positive	Neutral	Positive	Negative	Neutral	Positive	Positive	Positive	High Positive	Negative	Positive
31. Afforestation (high-cost)	Negative	High Positive	High Positive	Negative	Positive	Neutral	Neutral	Neutral	Negative	High Positive	Neutral	High Positive	Positive	Negative	Negative
32. Solar PV (residential)	Positive	Neutral	Neutral	Negative	Positive	Negative	High Positive	Positive	Neutral	Negative	Neutral	Negative	Neutral	High Positive	Positive
33. CCS (new build, oxyfuel, coal)	Negative	Neutral	High Positive	Negative	High Positive	High Positive	High Positive	Negative	Negative	Negative	High Positive	Positive	Positive	Neutral	Positive
34. Coal Mine, Oil Industry, High GWP, Wastewater Projects	Positive	High Positive	High Positive	Positive	Negative	Neutral	Positive	High Positive	Negative	Neutral	High Positive	Neutral	Positive	Negative	Neutral
35. Coal-gas Fuel Switch for Installed Fleet	Neutral	Negative	High Positive	Positive	Negative	Positive	Negative	Positive	Neutral	Positive	Positive	Positive	Negative	Positive	Positive
36. CCS (new build, pre-combustion IGCC)	Neutral	Neutral	Negative	Neutral	Positive	High Positive	Negative	Positive	Neutral	Negative	Neutral	Negative	Positive	Negative	Negative
37. CCS (retrofit, oxyfuel, coal)($107)	Positive	Negative	Neutral	High Positive	High Positive	High Positive	Neutral	High Positive	Neutral	Positive	Neutral	Neutral	Negative	Positive	Negative
38. Solar Thermal ($140)	High Positive	Positive	Neutral	Neutral	High Positive	High Positive	Negative	Negative	Positive	Neutral	Negative	Positive	Neutral	Negative	Negative
39. Gas Industry Project (high-cost)(>$1,000)	Neutral	High Positive	Neutral	Positive	Negative	High Positive	Positive	Neutral	Negative	Positive	Positive	Negative	Positive	High Positive	Neutral

The randomized data inserted in this table is for purposes of demonstration only and does not represent actual research.

developed in this study presents a summary of the more detailed analysis of development benefits created through the TNA.

Methodology

The data on the technology sheets reflect stakeholder responses to open-ended questions. To revise the visual in Figure 1 to reflect Montenegro's development priorities as identified by these stakeholders, we classified the responses into mutually exclusive categories of development impacts, reflecting the following methodology:

1. Employ when possible the stakeholders' original wording (translated to English), such as "improved quality of life," to retain the intended meaning.
2. Identify the impact as positive (+) or negative (-). Later in the TNA process, data will be provided to evaluate the magnitude of the positive or negative impact (high positive, positive, neutral, negative, high negative).
3. Use only data provided by the stakeholders. Because the data reflect responses to open-ended questions, the benefits are not necessarily established through a consistent framework. Nevertheless, this study does not attempt to extrapolate responses in one technology to another.

The technology sheets did not explicitly address ease-of-implementation. The sheets did reference assumptions about policy implementation, i.e., how the technology will be diffused, and responses, e.g., workforce training, were used to create categories for ease-of-implementation.

Results

This methodology produced a visual (Figure 2) with four social impacts, five economic impacts, five environmental impacts, and six ease-of-implementation impacts, marked by a +/- indicator for each technology that referenced that impact. References to each development impact varied—e.g., three technologies referenced rural development; eighteen referenced reducing dependence on imported fuels greenhouse gas reductions. The 'Environmental Impacts' and 'Ease of Implementation' categories include negative impacts for certain technologies.

The visual will then be returned to Montenegrin stakeholders to establish the relative magnitude of each impact, by technology. For example, although both 'Increasing diesel engine efficiency' and 'External wall insulation in buildings' indicate positive cost savings, the magnitude likely varies. The data on magnitude will then be added to a revised version of the visual in Figure 2, and with the addition of cost information,[5] will provide a final product intended to facilitate multi-criteria decision analysis.

Limitations

The quality of the visual relies on the quality of the input data on the technology sheets, compiled by a local consultant and then translated. As a result, the information is susceptible to translation errors and misinterpretation. Also, the impact statements prepared for Montenegro were highly qualitative and lacked specificity, as they were prepared as summary documents for a forthcoming detailed discussion at the TNA workshop on the development impacts of technology options. Therefore, impacts have not been systematically tabulated in the factsheets. At the TNA workshop development impacts of technology options will be discussed in further detail within the context of Montenegro, as a basis for scoring and weighting.[6] For this pilot, only the factsheets were available, and therefore a full impact assessment could not be incorporated in the visual. Figure 2 can be considered a first indication, and will later reflect the scores and weightings of the TNA workshop.

Moreover, the technology sheets, designed to present total costs of a technology at full penetration, were incomplete at this stage and lacked the cost information needed for the MAC curve. Such information would enable the user to simultaneously evaluate the development impacts of the least-cost technologies. Last, these technologies reflect impacts accruing to a subset of sectors, so benefits may not necessarily apply to an economy-wide analysis.

Lessons Learned

This pilot project identified ways to improve the process of developing the visual. In order to maximize the utility of the visual, this experience stressed the importance of developing the impact statements with further rigor. Specifically, the impact claims would benefit from a more detailed and a stronger causal foundation. This would allow for nuance in the range of the impact (high positive,

[5] Cost data can draw from existing MAC curves, where available. In the case of Montenegro, cost estimates will be derived during the next TNA workshop.

[6] The technologies will be compared with each other in terms of least (score 0) and most preferred (100); other technologies are scored relative to these two (e.g., 20, 50 or 95).

Fig. 2. First iteration of pilot visual for Montenegro based on technology sheets for priority sectors. Figure spans two pages.

	Social Impacts				Economic Impacts					Environmental Impacts					Ease of Implementation					
Technologies	Health [1]	Rural Development [2]	Energy Access	Quality of Life [3]	Employment	Competitiveness of Industry [4]	Cost Saving	Reduce Dependence on Imported fuels	Market Development Potential	GHG Emissions Reduction	Local Air Quality	Biodiversity Preservation	Water	Waste Management [5]	Awareness and Acceptance	Developed Market [6]	Low Investment Requirements	Low Technological Intervention Requirements	Supportive Policy Framework in Place	Trained Workforce
Aluminum Production																				
Increasing energy efficiency by interventions related to electrolyte composition	+					+	+			+	+	+			−	−	+	+		−
Inert anodes	+									+	+	+				−	+	−	−	−
Smelting process automation and improved process control	+					+	+			+	+	+			−	−	−	−	−	−
Transport Technologies																				
Transport management- intelligent transport systems			+	+		+	+			+							+	−		
Increasing diesel engine efficiency							+	+		+	+				+	+				
LPG Technology-Liquified Petroleum Gas					+					+	+						+	+	−	
Biofuels	+				+			+	+	+	+		+	+						
Hybrid vehicles			+	+	+		+	+		+	+								−	
Plug in hybrid				+	+		+	+		+	+				−				−	
Energy Consumption Technologies																				
Solar thermal system for hot water in domestic and service sectors					+		+	+	+	+					−	−			−	−
Heat pumps for space heating or cooling, water heating in domestic and service sectors					+		+	+	+	+		+			−	−			−	−
Eternal wall insulation in buildings					+	+	+	+	+	+					−	−	−			
High efficiency air conditioning systems in hh and service sector	+					+	+	+	+	+					−	−	−			

Technologies	Social Impacts				Economic Impacts					Environmental Impacts					Ease of Implementation					
	Health [1]	Rural Development [2]	Energy Access	Quality of Life [3]	Employment	Competitiveness of Industry [4]	Cost Saving	Reduce Dependence on Imported fuels	Market Development Potential	GHG Emissions Reduction	Local Air Quality	Biodiversity Preservation	Water	Waste Management [5]	Awareness and Acceptance	Developed Market [6]	Low Investment Requirements	Low Technological Intervention Requirements	Supportive Policy Framework in Place	Trained Workforce
Energy Consumption Technologies *(continued)*																				
High efficiency lighting in hh and service sector			+		+	+	+	+	+	+				−	−	−			+	
High efficiency appliances in hh and service sector							+	+		+					−	−	−			
Natural gas for cooking in hh and service sector				+			+	+		+	+	+			−	−	−			
Energy Generation Technologies																				
Hydro dams				+		+		+		+		−	−		−	−	−		−	
Small hydro	+	+		+	+			+	+	+	+								−	
On-shore wind								+	+	+		−			−	−		−		
Solar photovoltaic panels: concentrated, installed on building structures, grid-connected, off grid	+	+		+	+			+	+	+				−		−			−	
Solar thermal power: concentrating solar power							+	+	+	+										
Combined production of thermal energy and electricity from biomass-CHP					+	+	+			+	+					+				
Methane capture at landfills for electricity and heat		+				+		+		+	+		+	+	−	−			−	−
Gas power plant				+				+		+							−	−	−	
Carbon Capture and Storage										+							−			

1 Health impacts include improved health of local smelter workers in aluminum industry as well as general health improvements from improved air quality.

2 Rural development impacts include increased distributed generation as well as increased rural employment opportunities.

3 Quality of life impacts include improved travel/transportation experience, reduced noise, increased access to water recreation, and reduced burden resulting from firewood collection.

4 Competitiveness of industry impacts are anticipated in the following sectors: service, manufacturing, transportation, retail, civil engineering, agriculture, forestry/wood processing and tourism.

5 Waste management impacts include sustainable use of biproducts and traditional benefits associated with waste management.

6 Developed market characteristics include the existence of a mature private sector, technical institutes and adequate demonstration and acceptance of the technology.

positive, neutral, negative, high negative) and a higher degree of confidence in the claims, improving the visual's ability to assist decision-making. Furthermore, identified impacts should be systematically evaluated across technologies within the same sector (and across sectors when appropriate) in order to better compare technology options. The forthcoming TNA workshop will address this gap in data.

The next step will be to solicit feedback from Montenegrin stakeholders on the interpretation of their responses in Figure 2, and on the visual's overall utility as a tool to aid decision-making.

5. CONCLUSIONS

Achieving development goals is paramount to the success of a LEDS. Constructing a LEDS therefore requires a tool that enables governments to evaluate and prioritize technologies by their contributions to development goals. Yet leading optimization tools, such as MAC curves, exclusively focus on cost and carbon mitigation. This study proposes a tool that builds from the information in a MAC curve to communicate the range and magnitude of development impacts of each technology under consideration. To pilot this tool, the authors applied data on development impacts identified through the TNA in Montenegro to create a visual that reflects country-specific development goals. The visual will then be revised to reflect stakeholder feedback and new data established through the TNA that provides information on cost, GHG mitigation, and range and magnitude of development impacts.

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7. REFERENCES

(1) UNFCCC, The Cancun Agreements, Outcome of the work of the Ad-Hoc Working Group on Long Term Cooperative Action under the Convention. Decision 1/CP.16, UNFCCC document FCCC/CP/2010/7/Add.1, 2011, para. 6

(2) Kesicki, F and Ekins, M., Marginal abatement cost curves: a call for caution. Climate Policy. Volume 12, Issue 2, 2012

(3) UNDP, Handbook for Conducting Technology Needs Assessment for Climate Change. November 2010 http://unfccc.int/ttclear/pdf/TNA%20HANDBOOK%20EN%2020101115.pdf