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Societal benefits from renewable energy in Latin America and the Caribbean

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Contents

Abstract

Population growth and advances in quality of life in Latin America and the Caribbean (LAC) will require the region to rapidly increase its energy supply, even if major improvements in energy efficiency are attained. The region is characterized by a low-carbon power matrix and a potential to produce over 78 PWh from non-traditional renewable energy technologies (NRETs). However, bias toward fossil fuels and the perceived cost disadvantages prevent further market entry of renewable energy. Additional (societal) benefits of employing renewables are considerable but typically left out of cost comparisons. A consideration of these benefits may offer a rationale to promote investment and support regulations that would contribute to the deployment of these NRET technologies. We quantify societal benefits in terms of avoided costs (climate change avoided costs, avoided pollution control costs, avoided energy security costs) and economic benefits (improvements in the balance of payments and job creation). Results indicate that societal benefits are sufficiently large enough to compensate the cost disadvantage of solar and wind energy against fossil alternatives, justifying the eventual wholesale entry of these options.

Societal benefits from renewable energy in Latin America and the Caribbean

Background and Objective

Population growth and advances in quality of life in Latin America and the Caribbean (LAC) will require the region to rapidly increase its energy supply, even if major improvements in energy efficiency are attained. The region is expected to almost double its currently installed power capacity to about 600 GW by 2030, at a cost of about US$430 billion (bn).[1] This poses a challenge but also an opportunity to redefine the energy model for LAC, one that is consistent with global climate stabilization goals.

LAC is already characterized by a power matrix that is already low-carbon due to the anchor of large-scale reliance on hydrological resources that today provide over half of the overall power supply (see Annex 1). However, the anticipated growth in energy demand will require major additions to the existing generation capacity and consolidation of its firm capacity.[2] By 2050, under the current trend (as described in the business-as-usual "BAU" scenario from the IIASA GEA Model),[3] fossil fuels would increase their share of the power market by around 11% (from 37% to 41% of the generation mix), mainly on account of a substantial increase in the reliance on natural gas.[4]

By contrast, recent estimates indicate the region could produce over 78 PWh[5] (10^{15} W-hour) from solar, wind, marine, geothermal and biomass energy. The corresponding nominal peak capacity for the full deployment of this resource could be about 34 TW[6] –or almost seven times current world installed capacity, and well above any foreseeable demand. Furthermore, these resources constitute a near zero carbon option from an indigenous energy resource without an expiration date that could bring substantial societal benefits, including energy security, local and global environmental benefits, domestic job creation, and improved balance of payments, amongst others.

Despite this potential, significant barriers prevent further market entry of renewable energy. The most important relates to the intrinsic bias in the power sector toward continuing use of fossil fuels. This inertia is evident in regulations for expansion that favor power projects with lower initial capital costs and firm capacity, even despite higher operational costs over the long run. In addition, the cost disadvantage of renewables has been widely argued as a reason to stay the course in countries with other pressing development needs. Nevertheless, on this last point, results from recent tenders in Uruguay, Chile and Brazil suggest that the cost

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[1] Yépez-García et al. (2010).

[2] This need is magnified by climate impacts on hydropower availability. See Ebinger and Vergara (2011) for a discussion on this issue.

[3] Defined by the IIASA GEA Model's 'counterfactual' pathway. For details on the IIASA GEA model counterfactual pathway, or 'BAU trajectory', see Annex 4.

[4] As presented in Vergara et al. (2013b).

[5] Hoogwijk and Graus (2008), Poole (2009), ICA (2010), Meisen and Krumper (2009).

[6] Capacity factor values taken from assumptions made by Hoogwijk and Graus (2008) and NREL (2010). Energy Technology Cost and Performance Data. Available at: http://www.nrel.gov/analysis/capfactor.html

disadvantage is being eliminated as technology advances and field experience strengthens the financial case –at least for wind and photovoltaic-power plants.[7]

In general, however, the additional (societal) benefits of employing renewables are typically left out of such cost comparisons and, as a result, often do not enter into the decision-making process. A solid quantification of these benefits may offer decision-makers a rationale to promote investment and support regulations that would ease market entry of these NRET technologies. There is a limited body of literature analyzing these aspects (e.g. ASP 2005, Beck 2009, Nolan 2011, and Brown 2011),[8] but these studies are mainly technology and country/location specific and consider only a limited number of societal benefits, most of them focusing on emission reductions. Furthermore, their assumptions are not homogenous and their methodologies are often not compatible, undermining rigorous comparisons. Therefore, there is a need for a more thorough monetization of these benefits for LAC.[9]

This study intends to contribute to a broader knowledge of the benefits associated with the use of non-traditional renewable energy technologies (NRETs) in the power matrix of LAC. To this end, it examines to what extent societal benefits –defined as those that accrue to the national economies when shifting away from fossil fuels– are large enough to justify the eventual wholesale entry of NRETs including solar, geothermal and wind.[10] For this purpose, the analysis first makes a comparison of fossil fuel and NRETs on the basis of the levelized costs of electricity (LCOEs), and then proceeds to identify and quantify potential societal benefits of NRET deployment in LAC.

Levelized Costs of Electricity, Avoided Costs and Economic Benefits

LAC-specific estimates of costs, benefits and LCOEs of energy sources for the aggregated LAC regional power sector are generated by using scenario projections data from the IIASA Global Energy Assessment (GEA) Model.[11] This model scenario approach not only captures the various impacts of NRETs via their deployment in the electricity sector but also the synergistic effects that NRETs can have in combination with other activities such as the electrification of transportation.[12]

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[7] Vergara et al. (2013a).

[8] Table A2 in Annex 2 summarizes the findings of these studies.

[9] These and other surveyed studies and estimates –with the exception of Kammen et al. (2006) and Wei et al. (2010)– tend to use an value 'build-up" accounting method that focuses on NRET deployment in small increments, typically at the single plant or project level, within a very specific narrow environment (like a US state, or regulatory region). IRENA and European estimates from the German case, use similar methods (although the former aggregates and levelizes available empirical data across LAC). Discrepancies in definitional categories and assumptions often make comparisons of LCOEs and societal benefits in, and across, most such studies problematic (a difficulty overcome in a scenarios-based methodology).

[10] This analysis builds upon the work by Vergara et al. (2013).

[11] Annex 3 presents details of the LCOE methodology. See Annex 4 for a description of the comparison approach between the GEA Model 'business as usual" –or BAU– scenario trajectory and the GEA Mix scenario pathway used in this study.

[12] Both power generation and transport are the fastest growing sectors in terms of carbon footprint in the region. A major drive toward a renewable power matrix, would enable efforts to electrify other sectors of the economy, such as transport as part of a climate-responsible pathway of development.

Levelized cost of electricity (LCOE)

Costs of power generation among alternative technologies are estimated using the LCOE. The LCOE takes into account lifetime costs and allows for a direct comparison in terms of energy costs per kilowatt of electricity generated (US$/kWh). In this study, the LCOE for the entire LAC power sector serves as the basic reference point for the further calculations of the LCOEs of particular power sources (see Annex 3 for a detailed explanation). The estimation of societal benefits is then built directly upon this base, allowing for a direct US$/kWh comparison between costs (LCOEs) and societal benefits (avoided costs and economic benefits).

Societal benefits

Societal benefits, estimated as the sum of avoided costs and economic benefits,[13] are measured in monetary value per kilowatt-hour (US$/kWh), the common denominator in most energy discussions (equation 1).

$$\textit{Societal benefits} = \textit{Avoided costs} + \textit{Economic benefits} \qquad (1)$$

Avoided costs

Avoided costs consider the difference between (i) the future ‘business-as-usual” level of costs associated with the fossil fuel-dominated energy system, and (ii) those required by a future energy system pathway characterized by significant expansion of NRETs within the generation mix. The analysis considers three sources of avoided costs: avoidance of the financial costs of GHG emissions, avoidance of air pollution control costs and avoidance of costs associated with efforts to maintain energy security (equation 2).

$$\textit{Avoided costs} = \textit{Climate impacts} + \textit{Air pollution control} + \textit{Energy security} \qquad (2)$$

Where:

- *Climate impacts* considers the value of avoided (financial) costs of future carbon dioxide emissions.[14] Annex 4 presents a detailed explanation of the methodology used for these estimations.[15]
- *Air pollution* includes the avoided costs of ‘particulate’ pollution control equipment required (under BAU) to comply with WHO standards. This figure is a conservative estimate as potential sources of

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[13] ‘Avoided costs’ represent the quantities of savings and investment that can be channeled away from their projected BAU destinations in a fossil fuel-dominated energy system toward more productive and sustainable economic development efforts as a result of NRET deployment. On the other hand, ‘economic benefits’ represent further additional income (and savings) potentially available for investment in more sustainable economic development activity.

[14] Annex 4 presents an alternative method of framing the climate change benefits of NRETs: the avoided costs of climate change adaptation actions from a global temperature increase from 2°C to 4°C above pre-industrial levels. While the benefit expressed this way is much higher, it is also contingent on a range of global and LAC policy assumptions.

[15] In LAC, reducing energy emissions through NRET deployment is key as energy emissions are increasing much faster than land use change emissions and larger emissions cuts from energy could relieve the reduction pressures on the AFOLU sectors, where emissions reductions strategies are more complex and less tested. In this sense, NRET deployment in LAC offers an ancillary benefit by increasing the flexibility of LAC strategic efforts to meet climate change objectives.

significant costs are excluded such as avoided costs of pollution-induced health care (morbidity and mortality) or costs caused by lost productivity and/or ecosystem services.[16]

- *Energy security* quantifies avoided costs of energy insecurity based on the value of a fossil-fuel price hedge. This represents the cost of reducing the energy insecurity of exposure to price volatility of fossil fuels. The low end (US$0.0041/kWh) of the range quoted in Vergara et al. (2013) is utilized as proxy for energy security costs.

Economic benefits

Economic benefits represent additional net economic wealth creation, above and beyond that represented by the BAU trajectory, and independent of that produced by avoided costs or those included in traditional financial analysis (revenues from power produced or services provided). For simplification, and because of data limitations, the estimation is limited to benefits from the balance of payments and net job creation (equation 3).

$$\textit{Economic benefits} = \textit{Balance of payments} + \textit{Net job creation} \qquad (3)$$

Where:

- Balance of payments gain includes the economic benefits resulting from improvement in the national balance of payments (BOP) stemming from a reduction in energy imports or an expansion of exports.
- Net job creation employs a scenarios-based analysis to estimate net job creation by analyzing the difference in employment between the NRET scenario and the BAU trajectory, and applying energy technology ‘employment factors’ reported for developed countries (EWEA 1999, Kammen et al. 2006 and Wei et al. 2010). This value is then monetized using the economic annual value of a LAC job, measured as the projected evolution of LAC per capita income (market exchange rates, 2005 US$).

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[16] A more complete treatment of air pollution costs, in the context of Mexico City is described in World Bank (2002) where annual health benefits of improving air quality are estimated at US$760 million to US$1.49 billion (in 1999 U.S. dollars).

Results

Estimated LCOEs of LAC power sector are presented in Table 1. The cost differential of generating electricity from solar power in LAC compared to gas is US$0.14/kWh under the GEA Mix I pathway. The LCOE differential between wind and gas is US$0.067/kWh under the GEA Mix I pathway. As shown, our LCOEs estimates are also within the ranges reported by IRENA.

Table 1. Levelized Cost of Electricity (LCOE), Power Sector and Main Low Carbon Sources in LAC, 2010-2050

Generation Source	Own estimates US$2005/kWh	IRENA Database (US$/kWh)
Hydro		
BAU	0.051	$0.01 - $0.16
GEA Mix	0.052	
Gas		
BAU	0.064	$0.06 - $0.15
GEA Mix	0.064	
Solar		
BAU	0.154	$0.12 - $0.32
GEA Mix	0.204	
Wind		
BAU	0.196	$0.055 - $0.17
GEA Mix	0.131	
LAC Power Sector (total)		
BAU	0.057	
GEA Mix	0.066	

Source: IIASA GEA Model Projections Database (2013), IRENA (2013) and own elaboration.

Societal benefits in terms of avoided costs and economic benefits associated with the deployment of NRETs –specifically wind and solar– are presented in Table 2.

Avoided climate change damages are estimated at nearly US$ 0.14/kWh when taking into account avoided (financial) costs of emissions, but this value would be, conservatively, at least nearly twice as high if the avoided costs of adapting the region to climate change in a world with temperatures 4°C above pre-industrial levels (as compared to current 2°C estimates) are instead considered. Avoided costs of reducing particulate pollution to WHO standards, through non-NRET means (pollution control equipment) are valued at US$0.12/kWh.

The deployment of renewables could improve the current account of the BOP as a result of structurally displaced imports (or augmented exports) of fossil fuels, representing an avoided cost of US$0.01/kWh. However, NRETs would possibly also bolster the capital account through increased inflows of foreign direct investment (FDI) directly attracted by the prospects of such deployment which will result in a benefit greater than the previously indicated. An additional benefit in terms of net job creation –not including the indirect, induced or multiplied effects of job creation– is equivalent to US$0.01/kWh.

Results indicate that the aggregated value of societal benefits (US$0.285/kWh) is higher than the LCOE differential between most renewables and the main fossil sources in LAC (Table 2). That is, the total avoided costs and economic benefits from NRETs sufficiently compensate for the higher LCOEs of NRETs in comparison with those of fossil fuels.

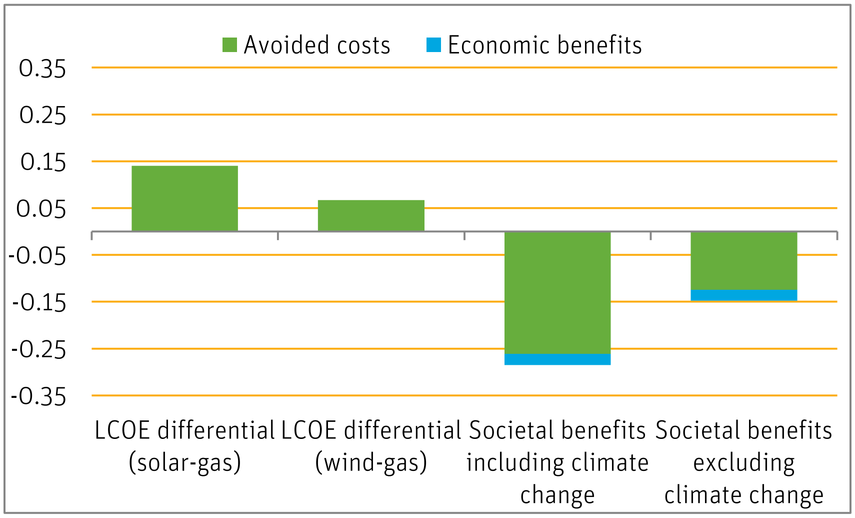
Table 2. Societal Benefits of Renewable Energies in LAC

	US$ cents/kWh
Avoided Climate Change Impacts	
Avoided Costs of Emissions	13.7
Avoided Costs of Climate Change Adaptation	21.5 or more*
Avoided Pollution	
Avoided Costs of Air Pollution Control Measures	12.0
Energy Security	
Avoided Costs of Oil Price Volatility (value of fuel price hedge)	0.0041-0.0095
Economic	
Balance of Payments Gains	1.22
Net Job Creation	1.16
Total with Climate Impacts	*28.5*
Total without Climate Impacts	*14.7*

Note: Estimation based on IIASA GEA Model Projections Database (2013), and Riahi, et al. (2012) for air pollution control costs.
*See Annex 4 for a methodological description of this alternative value for the climate change benefit; this value is not included in the total.

The societal benefit from NRETs (US$0.285/kWh) is higher than the cost disadvantage of solar versus gas in both BAU and GEA Mix scenarios (US$0.09/kWh and US$0.14/kWh respectively) – even if the climate change benefit is excluded from the total (see Figure 1). The same conclusion is valid for wind power: the wind-gas LCOE differential (US$0.132/kWh under BAU and US$0.067/kWh under GEA Mix I) is lower than our conservative estimation of societal benefits (US$0.285/kWh), even excluding climate change (US$0.147/kWh).

Figure 1. Estimate of LCOE Differentials Compared with Societal Benefits



Key Findings

Even when only partially and conservatively estimated, the societal benefits of NRETs in LAC are sufficiently large enough to justify the eventual wholesale entry of these technologies. This is true even if avoided costs of climate change are excluded from the total estimate. Hence, the magnitude of the benefits accrued to society from NRET deployment fully support public policy and regulatory actions to facilitate the adoption of these technologies. Understanding the magnitude of these benefits is also useful when planning for removal of subsidies for fossil fuels in LAC.

The results also reveal significant positive synergies in LAC from the simultaneous pursuit of NRET deployment and the mass electrification of the transport sector. The inclusion of synergy gains from electrification could potentially double all of this study's estimated avoided costs and economic benefits from NRET deployment.[17] This is because the displacement of fossil fuels from transportation would in turn be associated with additional societal benefits to be accrued through the type of avoided costs and economic benefits described above and possibly others such as avoidance of domestic refining costs and associated health related expenses.

Furthermore, the IIASA GEA model only considers NRETs in a 'non-distributed' deployment (i.e. solar and wind 'plants'). However, a NRET deployment strategy which included a significant portion of 'distributed' NRETs would potentially lower NRET LCOEs significantly, particularly with respect to future generation, transmission and distribution investment costs that will be required without deployment of 'distributed' NRETs. 'Distributed' NRETs would provide an additional advantage in terms of the LCOE differential with fossil fuels.

Looking Ahead

Future research is required to assess the LAC-wide energy security costs and the value of the fossil fuel price hedge specific to LAC. There is also a clear regional distinction within LAC that divides the region into the net importing region of Central America and the Caribbean, and the net exporting region of South America.[18] The IIASA GEA model provides projections for the world and its various regions (like LAC) but not for individual countries (or even sub-regions) within LAC. Therefore, a more precise quantification of energy security and BOP benefits would have to be conducted at the national level across the region.

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[17] The results, as presented, only account for impacts directly stemming from deployment of NRETs in the electricity sector. However, the GEA Mix scenario pathway also incorporates a significant electrification of the transportation sector. The resulting impact of significant electrification accompanying NRET deployment typically at least equals those benefits coming solely from changes in the generation sector. This is because electrification also involves significant net job creation in the transportation sector and displaces fossil-based transportation fuels, thereby reducing emissions, pollution, energy imports and BOP deficits. See Annex 4 for details.

[18] A compositional problem for the quantification of such benefits exists while using IIASA GEA model's projections for the LAC compound diversity indicator.

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Annex 1: LAC Power Matrix

Table A1. LAC Power Matrix by Source

	1984-1987		2010	
Electricity Output in GWh	182,300.49	100%	1,343,891.00	100%
Coal and coal products	4,904.50	3%	71,760.00	5%
Peat	-	0%	-	0%
Crude, NGL and feedstocks	-	0%	-	0%
Oil products	50,948.61	28%	139,851.00	10%
Gas	20,516.25	11%	316,466.00	24%
Nuclear	259.00	0%	27,573.00	2%
Hydro	103,854.71	57%	728,906.00	54%
Geothermal	156.00	0%	9,892.00	1%
Solar/wind/other	-	0%	4,605.00	0%
Combustible renewables and waste	1,661.42	1%	44,838.00	3%

Source: IEA. Electricity Statistics, http://www.iea.org/statistics/topics/Electricity/, 2013.

Annex 2: Societal Benefits of Renewable Energies

Table A2. Societal Benefits of Renewable Energies:
Value Build-up Matrix, Selected Estimates for Europe, the US and LAC

Societal Benefits valued in:	Beck (2009)[a]	ASP (2005)[b]	Nolan (2011)[c]		Wiesmeth and Golde (2011)[d]	Brown (2011)[e]
US cents/kWh	Solar, Arizona	Solar, US	Solar, Texas	Wind, Texas	Biomass	Wind, Brazil
Climate Change						
Emissions		0.3-1.9/kWh	0.28-3.6/kWh	0.28-4.00/kWh		
Energy Security						
Volatility of oil prices/value of fuel price hedge		0.4-1.0/kWh (gas)			4.0/kWh (oil)	
Pollution		0.01-1.9/kWh				
Economic						
Net job creation						3.7 jobs/MW
Total	7.91-14.11/kWh	7.75-51.3/kWh	0.28-3.6/kWh	0.28-4.00/kWh	3.1 – 27.0/kWh	--

Sources:

[a] Beck. “Distributed Renewable Energy Operating Impacts and Valuation Study”, for Arizona Public Service, January 2009.

[b] Americans for Solar Power (ASP), “Build-Up of PV Value in California – Methodology,” 13 April 2005. www.suncentricinc.com/downloads/aspv2005.pdf

[c] Nolan. “Valuing the Wind: Renewable Energy Policies and Air Pollution Avoided,” 2011. UCSD.http://econ.ucsd.edu/~knovan/pdfs/Valuing_the_Wind.pdf

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Annex 3: Methodology- Levelized Cost of Electricity

In order to estimate societal benefits (both avoided costs and economic benefits), there is a need to estimate the levelized cost of electricity (LCOE) for the LAC electricity sector as a whole and for the principal current (and foreseen) non-NRET and NRET technologies within the LAC electricity mix. The estimated LCOE of total LAC power under the BAU trajectory is US$ 0.057/kWh (US$ 0.066/kWh under the GEA Mix pathway). Such calculations were made possible by extending, and inferring from, the IIASA Global Energy Assessment model projections for LAC.

The IIASA GEA Model's BAU Trajectory and GEA Mix pathway

The GEA model projects primary, secondary and final energy mixes; total energy system expenditures and investment (with a number of breakdowns which are either sufficient for such calculations or split further down by this study into the elements of the electricity mix, utilizing 'generation mix factors'); and a number of other relevant data parameters, including emissions, fossil fuel extraction, secondary energy trade, demographic trends, GDP and per capita income, for both a counterfactual (or 'business-as-usual' or BAU) energy trajectory and for a number of alternative scenario pathways.[19] The GEA provides such projections in ten-year annual data splits from 2010 to 2100 for both the world and a number of world regions, including LAC (for more on the IIASA GEA Model and the calculation of estimated societal benefits, see Annex 4).

The calculation of the LCOEs for the LAC electricity system as a whole is made by isolating the projected fixed and variable electricity costs for both the BAU trajectory and for the most central of the IIASA energy pathway scenarios: the GEA Mix scenario pathway (with advanced transportation: or GEA Mix I, in our study). The GEA Mix pathway is characterized by (1) a Pareto-maximized full portfolio of available technologies (meaning no a priori restrictions on the use of any particular energy source, with selection driven by open market choice), and (2) significant future electrification of the LAC transportation sector. Once projected costs have been identified from the model database, the exercise must be repeated for the projected LAC generation of electricity, under BAU and the Mix pathway. Later, after having quantified the LCOE of the LAC-wide electricity sector, similar exercises must be undertaken for each principal energy source of the current and future LAC electricity mix from 2010 to 2050.

This GEA Mix scenario pathway is revealing –and useful– when cast against the reference of the BAU trajectory. The most notable impact upon the LAC electricity mix as the result of any movement from the BAU trajectory to the GEA Mix pathway to 2050 is a significant expansion of NRETs (solar and wind) that crowds out much of what otherwise would have been (under BAU) a major expansion of gas. There are only minor variations in geothermal (which is slightly lower under GEA Mix than under BAU), biomass (slightly higher), nuclear (slightly lower), oil (basically no change, if slightly lower) and coal (somewhat lower). In the end, however, all such minor variations among these tertiary generation sources cancel each other out. Hydropower expands under

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[19] The model also includes information for other potential pathways (41 in total) that achieve an energy system transformation sufficient to reduce GHG emissions to international targets consistent with the 'two degree guardrail' (equivalent to 450ppm CO_2e), nearly eliminate energy poverty, improve energy efficiency rates by 20% to 50%, and meet projected energy demand at an average annual GDP growth rate of 3.5%.

both pathways to the same degree (no real change, if a slight increase), leaving the incremental expansion over BAU of solar and wind power in the GEA Mix pathway as a central determining variable in the quantification of the societal benefits of NRETs in LAC.

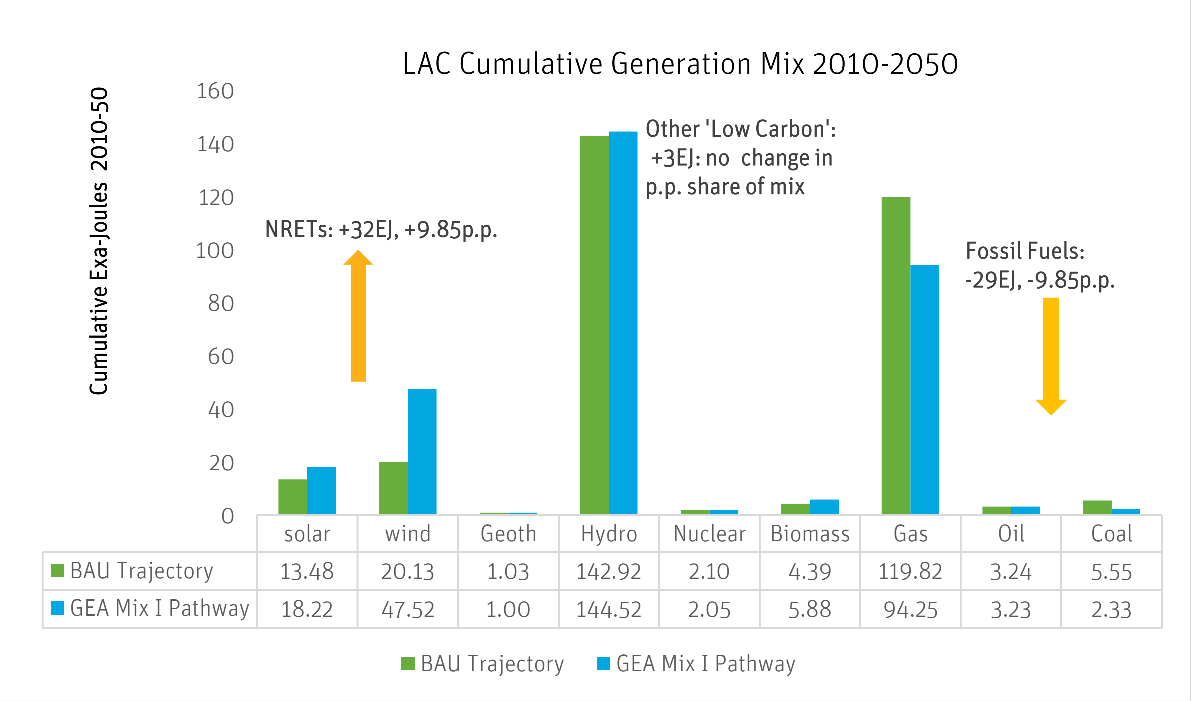
The main differences between the BAU trajectory (based on recent status quo trends) and the GEA Mix scenario are outlined in Table A3.a (see also Figure A3.a). NRETs share in the cumulative power mix to 2050 rises from 11% under BAU to 21% under the GEA Mix pathway. Fossil fuels, on the other hand, fall from 41% of the cumulative mix under BAU to 31% under GEA Mix. This crowding out of fossil fuels under GEA Mix, compared to BAU (a 10% swing in the cumulative mix from fossil fuels to NRETs) is a central variable upon which the societal benefits can be more easily isolated.

Table A3.a Principal Characteristics of the BAU Trajectory versus GEA Mix Pathway

NRETs in Generation Mix	BAU	GEA Mix
Cumulative 2010-2050	11%	21%
-Annual 2010	1%	1%
-Annual 2030	7%	14%
-Annual 2050	22%	39%
FF in power mix		
Cumulative 2010-2050	41%	31%
-Annual 2010	37%	37%
-Annual 2030	42%	34%
-Annual 2050	41%	26%
Projected GDP growth annual average	3.5%	3.5%
Efficiency	Historical rates of improvement	Final demand 41% below BAU levels
Demand-side investment 2010-2050	No demand-side investment	US$392bn investment in demand-side
CCS 2010-50	None	US$ 95bn investment in demand side
Emissions tons per capita in 2050	9.3	3.7 w/o AFOLU measures 2.0 w/AFOLU measures
Electrification	None	Significant electrification of transport

Source: IIASA GEA Model Projections Database (2013) and own elaboration.

Figure A3.a Displacement of Fossil Fuels from Generation by NRETs under GEA Mix I Pathway



	solar	wind	Geoth	Hydro	Nuclear	Biomass	Gas	Oil	Coal
🟩 BAU Trajectory	13.48	20.13	1.03	142.92	2.10	4.39	119.82	3.24	5.55
🟦 GEA Mix I Pathway	18.22	47.52	1.00	144.52	2.05	5.88	94.25	3.23	2.33

Source: IIASA GEA Model Projections Database (2013) and own elaboration.

The standard equation for LCOE calls for a cumulative sum of all costs (both fixed and variable) over the relevant lifetime/period in question (in this case 2010 to 2050) to be discounted back to net present value at a certain discount rate (in this case 5%),[20] and then divided by a cumulative sum of all the kWhs of power produced over the same period (also discounted back to present value). This was done by taking each GEA data projection split related to costs under the BAU trajectory and summing them, costs include:

- non-investment energy expenditures (i.e. operation and maintenance expenditures, both private and public, including support mechanisms) with an adjusted allocation to the electricity sector
- investment in non-fossil generation, with an adjusted split for each of the specific electricity sources
- investment in fossil generation, with an adjusted split for each of the particular fossil sources
- investment in transmission and distribution, along with storage, with an adjusted split for each generation source
- investment in fossil extraction and CCS, again with adjusted splits for electricity and particular generation sources).[21]

Adjusted splits are derived by applying, first, electricity's share in the secondary energy mix (approximately 33%) and, then by subsequently taking into account each electricity source's share in the current and future

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[20] A 5% discount rate was considered a conservative real rate of return. Annex 4 includes a sensitivity analysis aimed at identifying the impact upon LCOEs and relative levels of societal benefits of different discount rates.

[21] While the BAU trajectory does not foresee any energy investments on demand-side measures, the GEA Mix Pathway does, and therefore includes electricity-related demand-side costs to the tune of US$392bn cumulative from 2010 to 2050.

LAC electricity mix. Later, a similar summing exercise needs to be done for the projected generation of all LAC electricity sources to 2050.

The GEA Model projection database presents the isolated cost and generation data as units of billions of US (2005) dollars and exa-joules (EJ), respectively, projected annually for 2010, 2020, 2030, 2040, and 2050. Data series for each of the intervening years to 2050 were estimated, by calculating a linear movement of each data projection from one decade to the next. The adjusted 2010-2050 data series are then summed, discounted and slotted into the LCOE equation (aggregate discounted cost sums in the numerator, and the discounted total generation sum (converted from EJ to kWh), in the denominator), providing US$ cents/kWh LCOE for the entire LAC power mix.

Example LCOE calculation: The LAC-wide power sector under BAU and GEA Mix pathways

As the initial reference parameter, we calculated the estimated LCOE of the LAC electricity sector as a whole, as mentioned above. First we took from the IIASA GEA Model the projected figures under the BAU trajectory for investment in non-fossil electricity generation for 2010 (US$19.3bn annually), 2020 (US$ 12.7bn), 2030 (US$24.45bn), 2040 (US$34.4bn) and 2050 (US$30.9bn). Then we calculate, with the simplification of a linear assumption, each year's quantity (between decade marking annual figures) to produce annual total projections for each of the 41 years (from 2010 to 2050) adding up to a total of US$ 966.6bn. The same exercise (of 2010-2050 annual figures) is conducted for LAC-wide costs in the other realms of electricity costs: investment in fossil electricity generation (US$85.5bn), investment in transmission, distribution and storage (US$885bn), investment in fossil extraction dedicated to electricity (15% of the total – the share of electricity in total FF use –or US$529bn) and non-investment energy expenditures allocated to electricity (assumed to be one-third –electricity's share of the secondary energy mix in 2050– of the total for the entire energy sector, or US$1334bn). These cost subtotals are then aggregated to a total sum of US$3,800bn of total costs for the LAC wide electricity sector from 2010 to 2050 and then discounted back to 2010 at 5% discount rate resulting in US$931.12bn. This value –the net present value of projected total electricity costs from 2010 to 2050 under the BAU trajectory– is placed in the numerator.

The denominator is shaped by taking the projected levels of LAC-wide electricity generation under the BAU trajectory to 2050, and summing them in the same fashion described above: 4.57 exa-joules in 2010, 5.82 EJ in 2020, 7.4 EJ in 2030, 9.57 EJ in 2040 and 12.43 EJ in 2050, for a total of 312.66 EJ of power produced between 2010 and 2050. This sum discounts at 5% back to net present value at 58.83 EJ. Exa-joules can be converted to kWh by first multiplying by one trillion and then dividing by the conversion factor of 3.6 to yield kWh: in this case, 16.3 trillion kWh. This value – the net present value of projected LAC electricity generation under the BAU– is placed in the denominator.

Dividing US$ 931.12bn by 16.3 trillion kWh yields a LCOE of LAC-wide electricity of US$0.057/kWh –or US$57/MWh (Table A3.b). The same entire exercise is then conducted for the GEA Mix trajectory to yield a LAC-wide LCOE of electricity of US$ 0.066/kWh –or US$66/MWh (Table A3.c).

Table A3.b LAC Regionwide Levelized Cost of Electricity, 2010-50, BAU Trajectory

	2010	2020	2030	2040	2050	Total 41 years	Total Discounted 5%
Electricity generation EJ	4.57	5.82	7.38	9.57	12.43	312.7	58.83
Trillion kWh							16.3
Costs bn annual	57.01	55.85	91.21	130.24	150.01	3800.3	932.12
Non fossil fuel (FF) generation	19.26	12.71	24.45	34.41	30.92	966.6	
Trans, Distribution, Storage	15.84	16.46	20.74	27.1	32.55	885.04	
FF Generation	1.82	1.46	2.05	2.25	3.75	85.5	
FF Extraction	29.9	44.23	88.03	143.78	169.7	3758.3	
Linked to electricity	4.12	6.09	12.12	19.80	23.37	529	
CCS	0	0	0	0	0	0	
Linked to electricity	0	0	0	0	0	0	
Noninvestment Energy expenditures	48.12	57.58	95.71	140.15	178.54	4043	
Linked to electricity	15.88	19.00	31.58	46.25	58.92	1334.2	
Total LCOE LAC US$/kWh							0.057

Source: IIASA GEA Model Projections Database (2013) and own elaboration.

Table A3.c LAC Regionwide Levelized Cost of Electricity, 2010-50, GEA Mix Pathway

	2010	2020	2030	2040	2050	Total 41 years	Total Discounted 5%
Electricity generation EJ	4.57	5.56	7.38	9.86	13.62	319.10	58.16
Trillion kWh							16.15
Costs bn annual	57.39	54.46	91.60	134.96	179.19	4384.08	1074.36
Demand-side electricity invest						391.82	
Non FF Generation	19.27	14.91	23.83	34.72	48.89	1075.37	
Trans, Distribution, Storage	15.84	14.84	22.82	30.98	39.94	965.26	
FF Generation	1.84	1.04	2.51	2.17	2.18	77.30	
FF Extraction	29.9	26.97	45.74	58.57	51.83	1721.5	
Linked to electricity	6.21	5.60	9.50	12.17	10.77	356.75	
CCS Linked to electricity	0	0	1.64	3.91	7.93	95.10	
Noninvestment Energy expenditures	43.13	54.73	94.87	154.6	210.56	4310.52	
Linked to electricity	14.23	18.06	31.31	51.02	69.48	1422.50	
Total LCOE LAC US$/kWh							0.066

Source: IIASA GEA Model Projections Database 2013 and own elaboration.

For Annex 4, see online version of article.

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