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A general modeling framework to evaluate energy, economy, land-use and GHG emissions nexus for bioenergy exploitation

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HIGHLIGHTS

- The modeling framework addresses the energy, economy, emissions and land use nexus.
- Integration of technology roadmapping & scenario analysis for developing countries.
- Impacts of an accelerated deployment of bioenergy in Colombia until 2030.
- In Colombia, priority is biomethane production, power generation & CHP.
- By 2030, bioenergy alone will reduce emissions maximum 10% relative to baseline.

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ABSTRACT

This paper presents a modeling framework to address the energy, economy, emissions and land use nexus when exploiting bioenergy in developing countries. The modeling framework combines a qualitative and a quantitative element. The qualitative element integrates two components: (1) technology roadmapping to identify long-term technology targets through expert judgment and (2) scenario analysis to investigate different future storylines. The quantitative element comprises four integrated tools, namely the energy system model (ESM), the land use and trade model (LUTM), an economic model, and an external climate model. An overview of the modeling framework, scenario analysis, structure of the models, modeling techniques, mathematical formulations and assumptions is presented and discussed. The modeling framework is applied to the particular context of Colombia, as a case study of a developing country with large bioenergy potential. In this study case, the impacts that an accelerated deployment of bioenergy technologies might cause on the energy demand and supply, emissions and land use until 2030 are evaluated. Results suggest that a plan to exploit bioenergy in Colombia should prioritize the deployment of technologies for biomethane production, power generation & CHP, which can reduce more GHG emissions and more emissions per incremental hectare of land than first-generation biofuels. Moreover, while the share of bioenergy in the primary energy demand decreases in all the analyzed scenarios, it is possible to envision significant increases in the share of bioenergy in road transport energy demand, power generation and natural gas supply for scenarios implementing roadmap goals. In addition, impacts of El Niño oscillation on the dependence of hydro for power generation can be partly mitigated by exploiting the complementarity of hydro and bioenergy, which might result in a reduction of up to 5–6% in the demand for fossil fuels used in power generation in dry years. However, despite the ambitious goals proposed here, bioenergy alone cannot significantly reduce emissions by 2030 (maximum 10% reduction relative to baseline) and effective climate change mitigation requires a portfolio of additional measures.

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Nomenclature

Acronyms

BID	Inter-American Development Bank
BRICS	Brazil, Russia, India, China, South Africa
CHP	combined heat and power
CNG	compressed natural gas
COE	cost of electricity
DANE	National Administrative Department of Statistics, Colombia
DECC	Department of Energy & Climate Change
EIA	U.S. Energy Information Administration
ENSO	El Niño and La Niña southern oscillation
ESM	energy system model
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute
FFB	fresh fruit bunches (palm oil)
GCM	general circulation model
GDP	gross domestic product
GHG	greenhouse gas
IAM	integrated assessed model
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LCOE	levelized cost of electricity
LEAP	Long-range Energy Alternatives Planning System
LHV	lower heating value
LPG	liquefied petroleum gas
LULUCF	land use, land-use change and forestry
LUTM	land use and trade model
MME	Ministry of Mines and Energy, Colombia
NEA	Nuclear Energy Agency
NMVOC	non-methane volatile organic compounds
NOx	nitrogen oxides
PPP	purchasing power parity
Toe	ton of oil equivalent
UNEP	United Nations Environment Programme
UPME	Mining and Energy Planning Unit, Colombia

Symbols

A	dummy variable to estimate vehicle ownership
AL	activity level
BMV	blend mandate of biofuels by volume
C	installed power generation capacity
CC	capacity credit
CK	coefficient to evaluate the annual energy demand for cooking per household
Cov	supply coverage
D	population density
DC	total discounted cost
DE	decommissioning cost
Deg	factor representing the change in a property (e.g. efficiency, emission) as a technology ages
E	access to energy services (electricity and natural gas)
ECAa	energy consumption for appliances
ECApa	energy consumption for appliances per capita
ECCH	energy consumption for cooking per household
ECCI	energy consumption in agricultural industries
ECCp	energy consumption for cooking per capita
ECF	energy consumption by fuel for various sectors
ECL	energy consumption for lighting
ECLH	energy consumption for lighting per household
ECLp	energy consumption for lighting per capita
ECP	consumption of energy resources for power generation
ECV	energy consumption for a vehicle
ECWp	energy consumption for water heating per capita
EF	emission factor
EI	energy intensity
F	fuel cost
FE	fuel economy for a new vehicle
FS	floor space per person
FSQ	floor space quintile factor
GDP	gross domestic product
GDPp	gross domestic product per capita
GHG	greenhouse gas emission
H	number of households
HDD	heating degree days
HH	household expenditure
HHp	household expenditure per person
I	investment cost
IS	income share for different regions or quintiles
LHF	lighting hours factor coefficient
LHV	lower heating value
M	motorcycle ownership
MEF	multiplying emission factor for biofuels
Mil	mileage for a vehicle
OD	annual number of days demanding hot water
OM	operation & maintenance cost
OW	appliance ownership
P	population, e.g. number of inhabitants
PG	power generation
PL	peak load
Q	quintile number, i.e. 1, 2, 3, 4 and 5
R	dummy variable to estimate vehicle ownership
r	discount rate
RM	planning reserve margin
S	household size
Sales	number of vehicle sales
SH	vehicle share
Stock	number of vehicles
Sur	survival rate of vehicles
T	temperature
t	year
U	urban fraction of population
UEC	unit energy consumption by type of appliance
V	vehicle ownership
VE85	percentage of vehicles able to run with E85
VEFF	percentage of vehicles that are flex fuel
W	unit energy consumption per light bulb
x	mass content
α	parameter of Gompertz function
β	parameter of Gompertz function
ψ	saturation level of Gompertz function
λ	negative constant of Gompertz function
φ	negative constant of Gompertz function
θ	speed of adjustment
ε	random error
k	cost exponent in logit function
$k_{1,2,\ldots n}$	constant of Gompertz function
γ	cost sensitivity coefficient in logit function
μ	fuel share
ϑ	coefficient that influence the unit energy consumption in appliances
ζ	coefficient that influence the unit energy consumption in appliances
ξ	coefficient that influence the energy consumption by fuel for various sectors
∇	gradient to model differences in access to energy services across quintiles