



UNIVERSITY OF TECHNOLOGY SYDNEY
Faculty of Engineering and Information Technology

**WATER–ENERGY–FOOD NEXUS IN SUGARCANE
ETHANOL PRODUCTION IN THE STATE OF GOIÁS,
BRAZIL: A REGIONAL INPUT-OUTPUT ANALYSIS**

by

Rodrigo Augusto Bellezoni

A dissertation submitted in fulfilment of the requirements for the degree
Doctor of Philosophy (Energy Planning and Policy)

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Certificate of Original Authorship

I, Rodrigo Augusto Bellezoni, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Systems, Management & Leadership, Faculty of Engineering and Information Technology at the University of Technology, Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text. This thesis is the result of a Collaborative Doctoral Research Degree program with Federal University of Rio de Janeiro, Brazil.

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Format of the Thesis

This manuscript consists of a conventional thesis format and it is structured as a continuous series of sections, including:

- an introduction to the research study, a review of the literature and a justification of how it adds to knowledge in the field
- description of and justification for the research approach and methods
- a case study analysis
- presentation of results and discussion
- conclusion.

List of Publications Included

As a partial result of this thesis, an original article on the water-energy-food nexus approach was published in the *Biomass & Bioenergy* journal, as presented below:

Rodrigo A. Bellezoni, Deepak Sharma, Alberto A. Villela, Amaro O. Pereira Jr, ‘Water-energy-food nexus of sugarcane ethanol production in the state of Goiás, Brazil: An analysis with regional Input-Output matrix’, *Biomass & Bioenergy*, Vol. 115 (2018), pp 108-119.

Please refer to **Appendix XXII: Publications Included** to see this published article and the permission from the copyright owners to include an online version of it in this thesis. Additionally, refer to the appendix to check the contributions of each author to this article.

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Abbreviations/Glossary

ABC	Low carbon emission agriculture program
AEZ	Agro-ecological zoning
ANA	National Water Agency
ANP	National Agency for Petroleum, Natural Gas and Biofuels
BTL	Biomass-to-liquids
CAPEX	Capital expenditure
CBIO	Biofuel decarbonisation credit
CES	Constant elasticity of substitution
CCS	Carbon cost share
CGE	Computational general equilibrium
CGEE	Centro de Gestão de Estudos Estratégicos
CLEWS	Climate, Land, Energy and Water System
CMBC	Committee for the Monitoring of Biofuels and Fuels
CNI	National industry confederation
CNPE	National Energy Policy Council
CO _{2e}	Carbon dioxide equivalent
CONAB	Brazil's national supply company
COP 21	21 st Conference of Parties
CRA	Environmental reserve quota
DLUC	Direct land-use change
EMBRAPA	Brazil's federal agricultural research agency
EPE	Brazilian energy research company
ERQ	Environmental Reserve Quota
ETS	Emissions trading schemes
EVAC	Evaporation coefficient
EVAV	Volume of water lost by evaporation
FAO	Food and Agriculture Organization of the United Nations
FUNARBE	Federal University of Viçosa Support Foundation
GCM	General circulation models
GDP	Gross domestic product
GHG	Greenhouse gases
GIZ	German development agency Deutsche Gesellschaft für Internationale Zusammenarbeit
GO	Goiás State
GWP	Global warming potential
HEFA	Hydro-processed ester fatty acids
HLPE	High-level panel of experts
hm ³	Cubic hectometre
IAEA	International Atomic Energy Agency
IBGE	Brazilian Institute of Geography and Statistics
ICAP	International Carbon Action Partnership
ICIMOD	International Centre for Integrated Mountain Development

ICLFS	Integrated cropland-livestock-forestry system
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IISD	International Institute for Sustainable Development
ILUC	Indirect land-use change
IMB	Mauro Borges Institute
INPE	National Institute for Space Research
IO	Input-output
IOA	Input-output analysis
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
J	Joules
km ²	Square kilometre
LCA	Life cycle analysis
LEAP	Long-range energy alternatives planning
LHV	Lower heating value
LR	Legal Reserve
LUC	Land-use change
LULUCF	Land-use, land-use change and forestry
MAPA	Ministry of Agriculture and Food Supply
MAPBIOMAS	Annual land use and coverage mapping in Brazil
MBRE	Brazilian Emission Reduction Market
MCTI	Ministry of Science, Technology and Innovation
MME	Ministry of Energy and Mines
MSA	Multi-sectoral systems analysis
MuSIASEM	Multi-scale integrated assessment of society and ecosystem metabolism
NDC	Nationally determined contribution
NPCC	National Policy on Climate Change
NWRP	National Water Resources Policy
OPEX	Operational expenditure
PDE	Ten-Year Energy Plan
PMR	Partnership for Market Readiness Organisation
PNPB	Brazilian biodiesel production program
PPA	Permanent preservation area
PPP	Polluter pay's principle
PRBP	Paranaíba River Basin Plan
PROALCOOL	Brazilian National Alcohol Program
QAV	Aviation kerosene
PSA	Payment for environmental services
RBP	River basin plan
SEEG	Emissions estimating system for GHG
SEI	Stockholm Environment Institute
SHP	Small hydroelectric plants
SIP	Synthesised iso-paraffin

SIRENE	National emissions record system
Tg	Teragrams
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNICA	Sugarcane Industry Association
WCI	Western Climate Initiative
WEAP	Water evaluation and planning system
WEFN	Water-energy-food nexus
WMU	Water management unit
ZAE Cana	Sugarcane agro-ecological zoning

ABSTRACT

WATER–ENERGY–FOOD NEXUS IN SUGARCANE ETHANOL PRODUCTION IN THE STATE OF GOIÁS, BRAZIL: A REGIONAL INPUT-OUTPUT ANALYSIS

by

Rodrigo Augusto Bellezoni

Concerns about the impact of biomass growth for biofuel production emphasise the importance of planning the expansion in energy crops, taking into consideration water, energy and land resources, as well as greenhouse gas emissions (GHG). This research analyses the impacts of first-generation sugarcane ethanol expansion in the Paranaíba basin (Goiás State, Brazil), focusing on how future demand for ethanol could affect the socioeconomic, energy and environmental outcomes in the region. An economic-ecological input-output (IO) framework was applied to develop a water-energy-food nexus (WEFN) analysis on ethanol production. A Leontief IO price framework was also applied to analyse the economic and environmental impacts of changes in factor input prices, resulting from the imposition of a US\$10 carbon tax. The results show that sugarcane expansion would apparently have little significant direct impact on land and water availability in the Paranaíba basin, when price change effects (through a carbon tax policy) are not taken into account. Conversely, however, when a US\$10 carbon tax policy is applied, the negative environmental impact (of economic changes) of expanding sugarcane crops in Goiás would be 5-fold higher as compared with the non-carbon pricing scenarios; thereby significantly changing the big picture of promoting biofuels expansion in the state when physical and economic models are jointly applied. Therefore, any ethanol scenario under a carbon pricing initiative would turn into a high-impact development option for Goiás, showing much higher environmental impacts when compared to non-carbon-pricing scenarios and the long-term environmental impacts would offset any economic gains. This significant difference between the results of a physical approach and a price approach is an important way of assessing environmental impacts in terms of their economic implications, and a means of aligning both results and policy recommendations more closely to reality. Additionally, the impacts on the return of a sector's value-add show that no Goiás' economic sector would be significantly

impacted in carbon price scenarios up to US\$10/tCO_{2e}, except for the *Agricultural* sector; this would face huge challenges even under 45% and 35% emissions reduction scenarios, with impacts of 17% and 20% in value-added terms, respectively. Finally, the unintended impacts of expanding biofuels, such as the possibility of indirect deforestation and its related GHG emissions, must always be considered before promoting sugarcane expansion in the Paranaíba basin. Therefore, the WEFN analysis is a valuable tool for guiding the sustainable management of natural resources, including water, energy, land use and GHG emissions. In particular, the hybrid extended IO-WEFN framework is useful for designing effective biofuel policies and collectively addressing impacts on environmental, social and economic spheres, in a local or broader context.

Dissertation directed by Professor Deepak Sharma
School of Information, Systems & Modelling (ISM)