The Abdus Salam International Centre for Theoretical Physics

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Joint ICTP-IAEA Advancing Modelling of Climate, Land-use, Energy and Water (CLEW) Interactions

7 - 11 October 2013

MAURITIUS - CLEW Case Study
Assessing Interdependencies among Energy, Water, Land-Use and Climate Change in Mauritius

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MAURITIUS



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Assessing Interdependencies among Energy, Water, Land-Use and Climate Change in Mauritius

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Content

- Mauritius background: Status of CLEW resources & challenges
- Policy questions and policy goals addressed under Clew study
- Scenarios assessed
- Methodology
- CLEW Modelling tools
- Model Interactions
- Results of different scenarios
- Key findings
- Conclusion
- Benefits : CLEW approach

Mauritius – Background

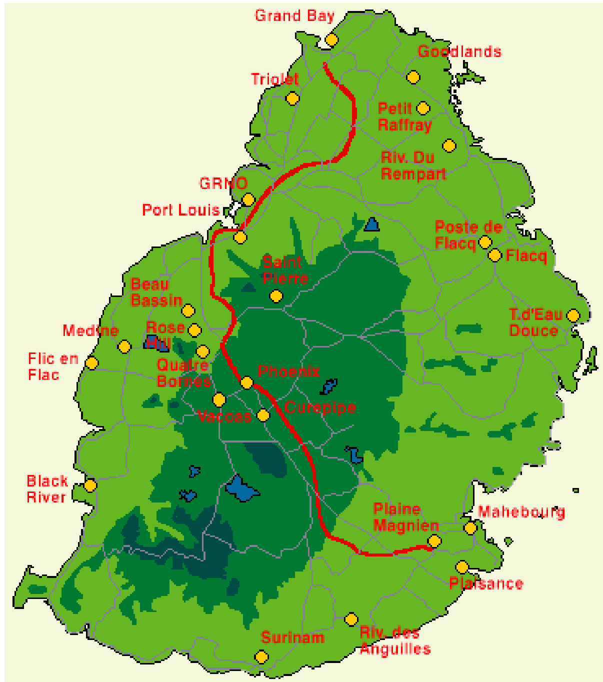
- Small island with clear boundaries
- Population 1.2 M

Inherent environmental vulnerabilities as SIDS:

small land area, susceptibility to natural disasters, geographical isolation, limited natural resources and sensitive ecosystems

Due to reliance on external sources of fuel and food - Vulnerable to external shocks :

- Volatile of oil prices
- High and volatile food prices – food insecurity
- External factors affecting Tourism sector and textile exports



- Agriculture is dominated by sugar cane which occupies 80 % of cultivated land (70,000 ha) but contribute only 3.8 % the GDP
- Net food importer (70% of national requirements)

- EU sugar reform: 36 % drastic reduction in sugar price
- Abandonment of some 8000 ha of sugar cane land over last 7 years
- Govt. policy to increase food security

Basic Statisitis

Indicators	Units	2002	2011
Population (mid-year)	0000	1,210	1,286
Population annual growth rate	%	0.9	0.4
Area under agriculture	Ha		
Irrigated land	Ha	21,222	19,885
Forest area (as a % of total land area)	%	30.4	25.6
Agriculture as a % of GDP	%	*5.9*	*3.7*
Employment in Agriculture (as a % of total)	%	9.6	7.9
Per capita carbon dioxide emission	Tons	2.2	2.8
Mean annual rainfall	mm	2,082	1,945
Annual freshwater abstraction	Mm	726	571
Daily per capita domestic water consumption	Litres	157	162
Total electricity generated	Gwh	1,949	2,730
Per capita primary energy requirement	Toe	1.0	1.1
Per capita final energy consumption	Toe	0.6	0.7
Energy intensity (Toe per Rs100,000 GDP at 1990 prices	Toe	1.1	1.4

CLEW constraints

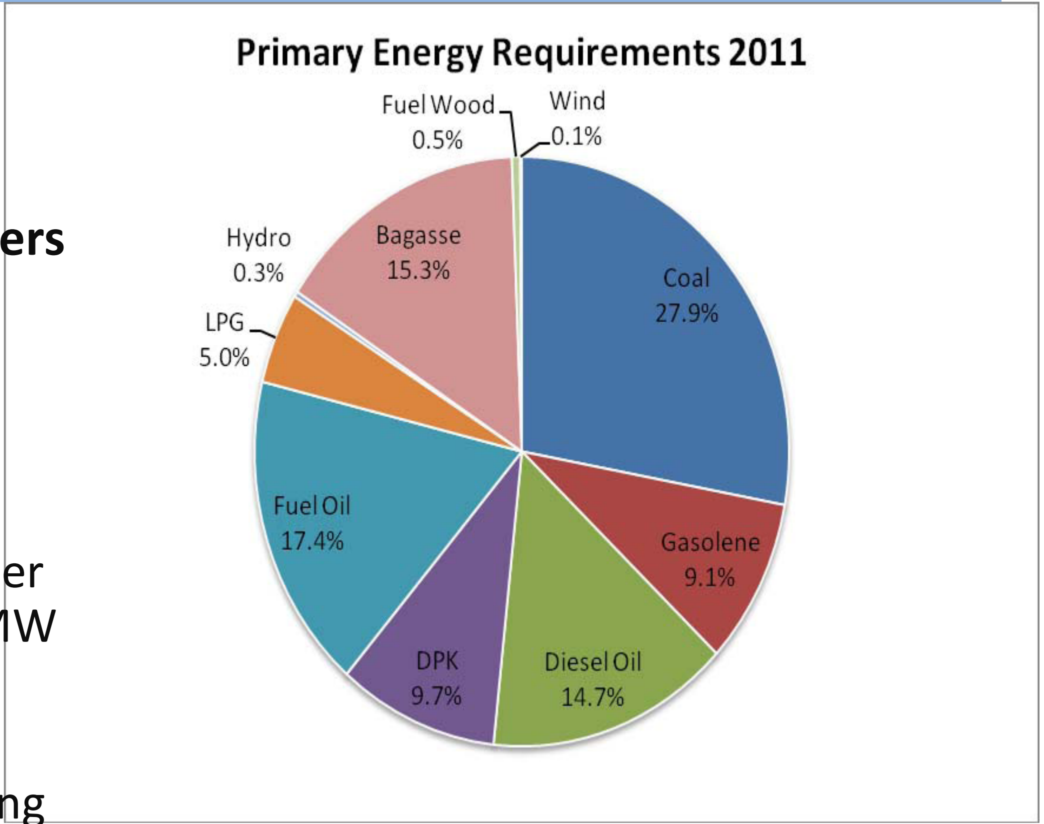
Clew Resources	Level of constraints	
Climate	**High**	**-As SIDS , highly vulnerable to climate change, particularly water, agriculture, fisheries and tourism sector** **- Estimated 14 % decrease in annual rainfall by 2040**
Land use	**Intermediate**	-Limited land area (1865 Km^2) - Agriculture is dominated by sugarcane occupies 80 % of cultivated area
Energy	**High**	**-83.8 % of energy supply met by imported oil, gasoline, gas and coal** **-Remaining 16.2%** - Local renewable sources (bagasse (94.4%) and 5.6 % from hydro, wind, landfill gas and fuelwood) **-Bagasse contributes to 17 % national energy production** **- Transport and Industries – 2 largest consumer**
Water	**Intermediate**	**- Depend on rainfall for fresh water resources** **- Classified as water stress country (UNDP)** **- Agriculture consumes 48 % of its freshwater resources**

Energy sector

National Energy production

- **45 % by Central Electricity Board**
  (from Oil, Hydro(5 %))
- **55 % by Independent Power Producers (IPPs)**
    - bagasse and coal
    - solar, wind, waste

    (still not yet fully exploited)



Energy demand increasing at rate of 5 % per year with peak power demand of 430.1 MW in 2012

- **Transport and Manufacturing** industries:two largest energy-consuming sectors accounting for 50.5% and 25.7% respectively
- Energy consumption in Agriculture: mainly for irrigation (pumping) and mechanical operations

National Long Term Energy Strategy (2009 - 2025)

- Reduce dependence on fossil fuels
- Increase the share of renewable energy from 17.5 % to 35 % in 2025
-Promote energy efficiency and conservation

Mauritius – CLEW case study

Government policy goals

Making Mauritius a sustainable island focussing on reducing dependence of fossil fuel and reducing GHG emission …

Policy question: Should sugar cane be processed into ethanol instead of sugar?

AIM of using the CLEW modelling framework is to assess the energy,
Water and land-use system in the context of **different scenarios**

1. Reduce gasoline imports by producing ethanol, displacing sugar exports

2. Considering different energy system alternatives and land use options (e.g. different crops) under uncertain future dryer climatic conditions

Quantify

- CLEW resources
- Economic implications under different conditions (technological and climate change)

Methodology

- Development and calibration of water, energy and land use model using 10 years data (1996- 2005)
  - WEAP - water
  - LEAP - energy
  - AEZ - land production planning

- Selective integration of the different models using common assumptions and "soft" linkages to calculate:
  - What are the changes in total costs?
  - What are the influences to the local water balance?
  - How changes the local energy balance?
  - What are local and externally induced GHG emissions?

Scenarios

Scenario 1 (without climate change): Maintaining sugar cane production

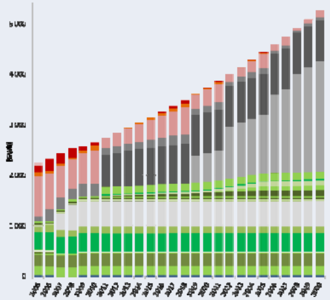
BAU	Producing sugar and using bagasse for electricity generation
Gen 1 ethanol	Converting sugar production to Generation 1 **(Gen 1) Ethanol** production & bagasse used for electricity production
Gen 2 ethanol	Use new process to increase ethanol yield (Using both sugar cane and bagasse for **Gen 2 ethanol** production)

Scenario 2 (with climate change) : Water-Stress (dryer future)

BAU +CC	**Maintain cane yields for sugar with effort to meet crop water requirement**
Gen 1 +CC	**Maintain Gen 1 ethanol production from sugar with effort to provide for water**
New biofuel crop +CC	**Considering an alternative drought tolerant crop for ethanol production**

Methodology

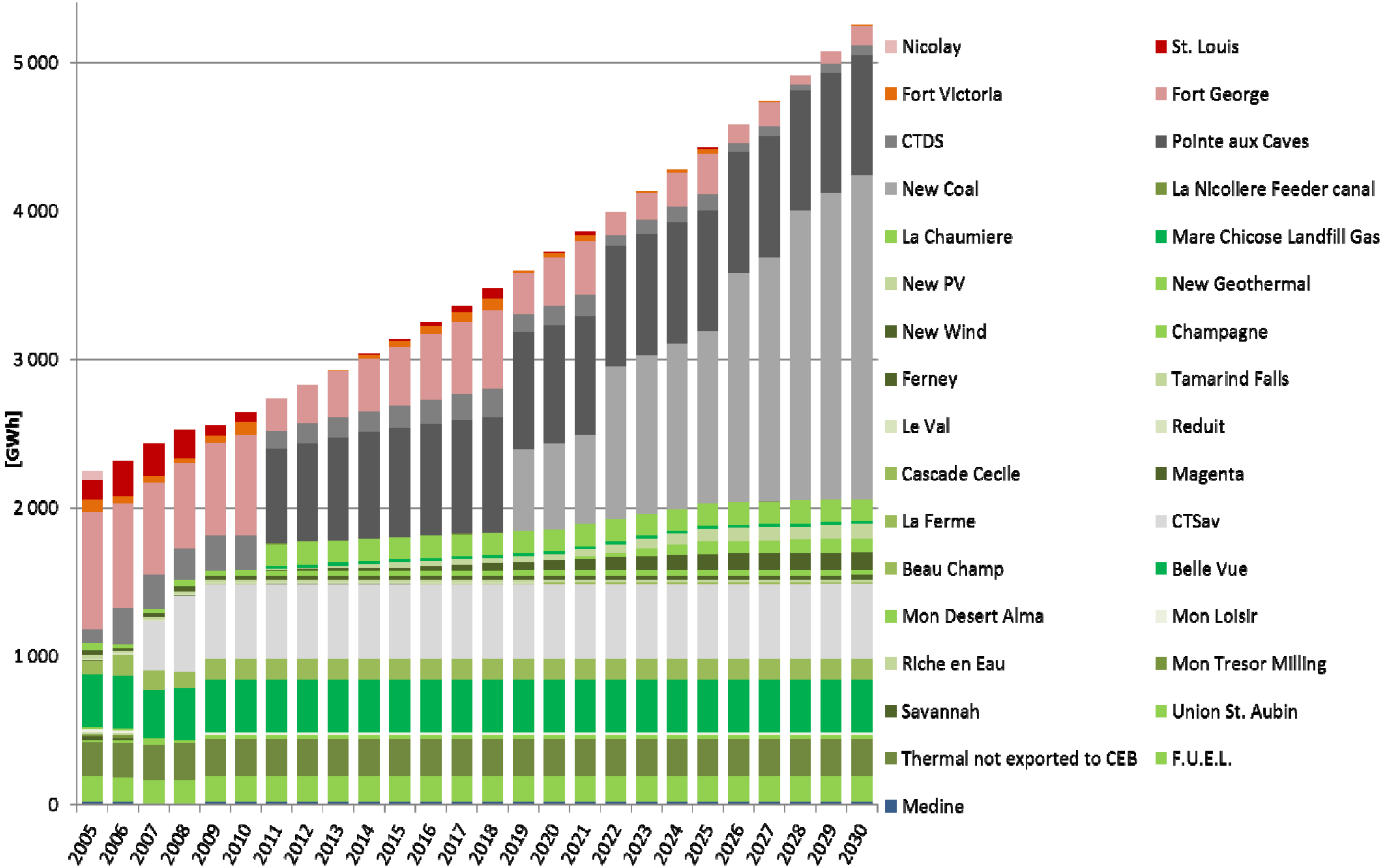
Development and calibration of water, energy and land use model using 10 years data (1996- 2005)

Energy	Water	Land Use
LEAP	Water Evaluation And Planning WEAP	AEZ
	Water availabilty for each point in the system (on the island) under different conditions / szenarios	Grid map of Mauritius showing optimal crops, potential water use, and potential yield including a „Crop calendar“

- Selective integration of the different models using common assumptions and “soft” linkages to calculate:
  - What are the changes in total costs?
  - What are the influences to the local water balance?
  - How changes affect the the local energy balance?
  - What are local and externally induced GHG emissions?

Modelling Tools used ...

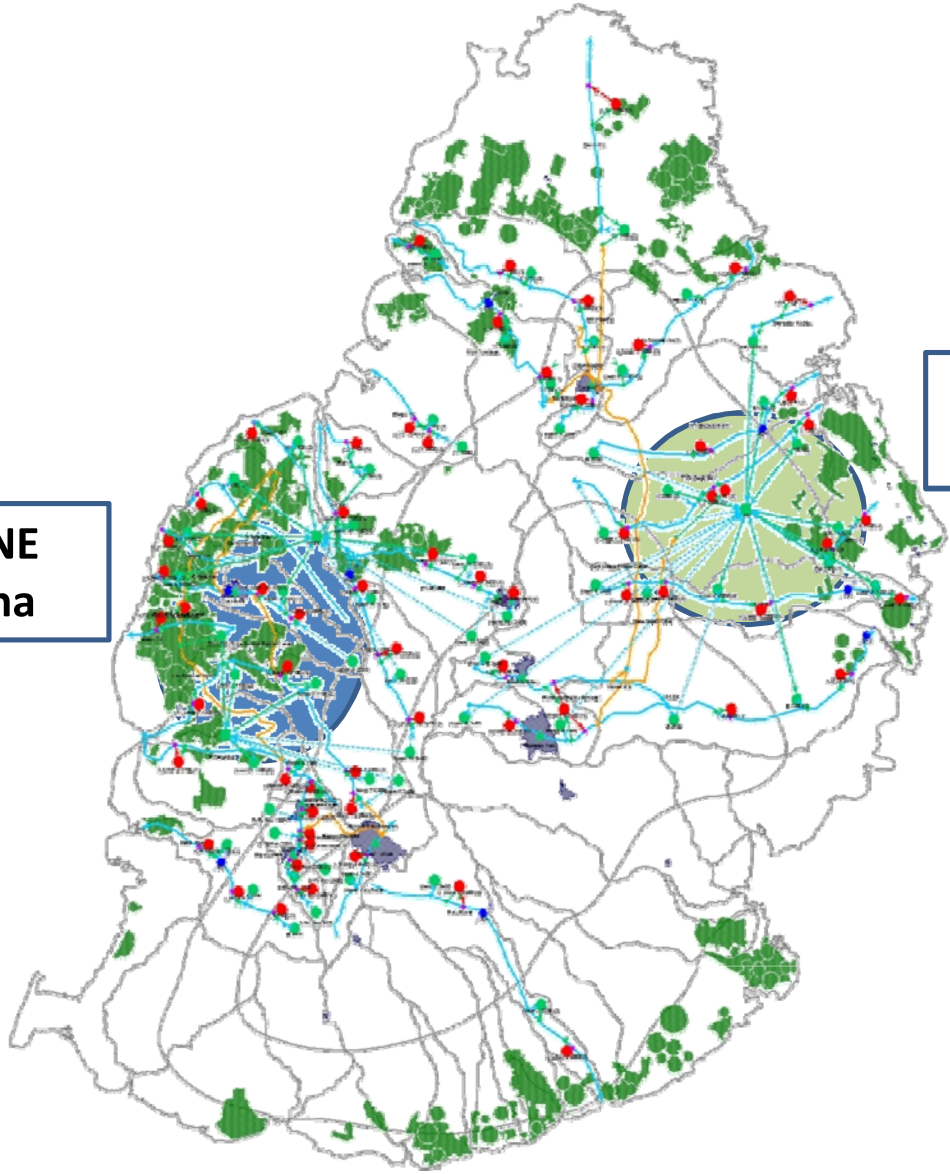
	Energy	Water	Land Use
Model	**LEAP(SEI)**	**WEAP(SEI)**	**AEZ(IIASA)**
Input	• Energy demand (current / future, load curves), • Existing + planned Power plants, • Imports and exports, and resource availability, • GHG emission factors	• Climatic data (1996 – 2005):Rainfall, min & max temperature, humidity , evapotranspiration, ..., • Land cover data, • Definition of catchment areas • Main rivers & reservoirs plus stream flow data and reservoirs levels • Soil data and water avail., • Water consumption, • Desalination and hydropower	• Climatic data (plus projections), • Land cover data, • Soil data,
Output & Results	• Future optimal energy mix under different conditions, • Future GHG emissions • Costs	• Water availability under different scenarios (CC and/or w. demand change) for ALL points in a modelled system	• Crop Map (most suitable crops per area) • Crop Calendar • Future water demand • Fertilizer demand



[GWh]
5 000
4 000
3 000
2 000
1 000
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
Nicolay
St. Louis
Fort Victoria
Fort George
CTDS
Pointe aux Caves
New Coal
La Nicoliere Feeder canal
La Chaumiere
Mare Chicose Landfill Gas
New PV
New Geothermal
New Wind
Champagne
Ferney
Tamarind Falls
Le Val
Reduit
Cascade Cecile
Magenta
La Ferme
CTSav
Beau Champ
Belle Vue
Mon Desert Alma
Mon Loisir
Riche en Eau
Mon Tresor Milling
Savannah
Union St. Aubin
Thermal not exported to CEB
F.U.E.L.
Medine

Water
Evaluation
And
Planning

WEAP

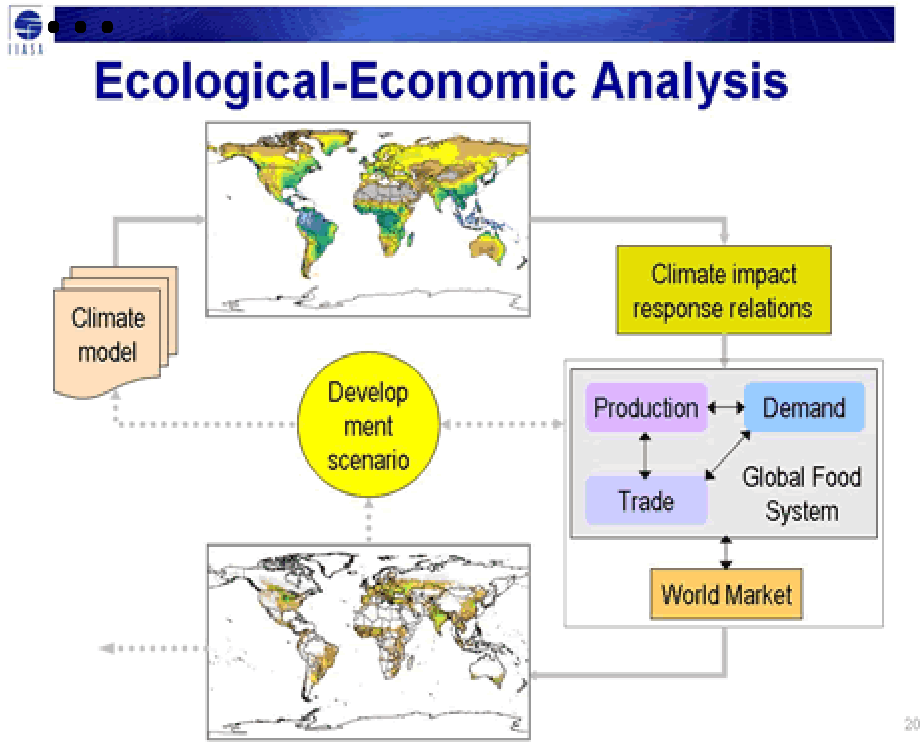


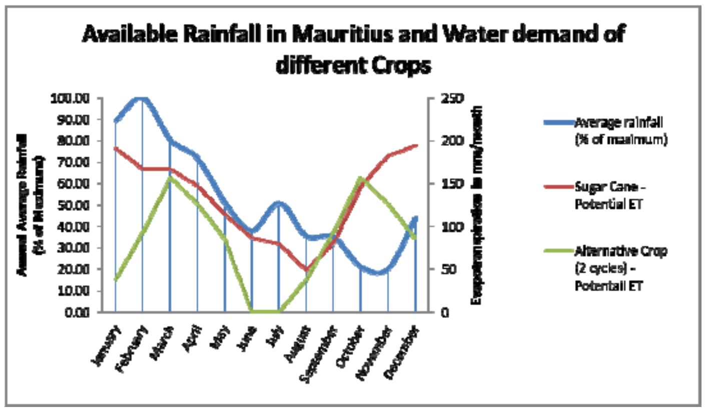
MEDINE
5700 ha

FUEL
9500 ha

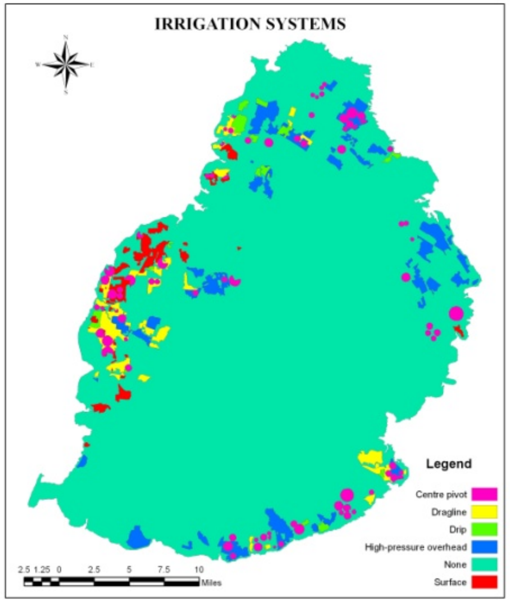
AEZ - The Land-Use Model

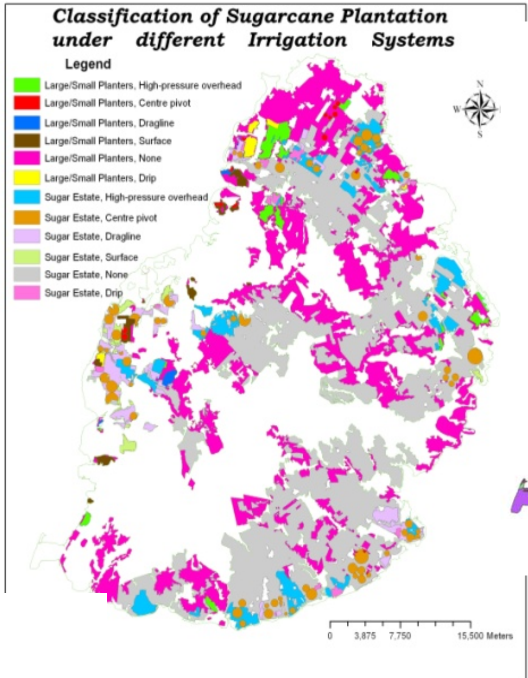
- Input:
  - Climatic Data
  - Detailed soil map and data from soil profils
  - Slopes and marginal land
  - GIS data for landcover
  - Irrigated areas
- Output:
  - Grid map of Mauritius show optimal crops, potential water use, and potential yield, plus crop calendar

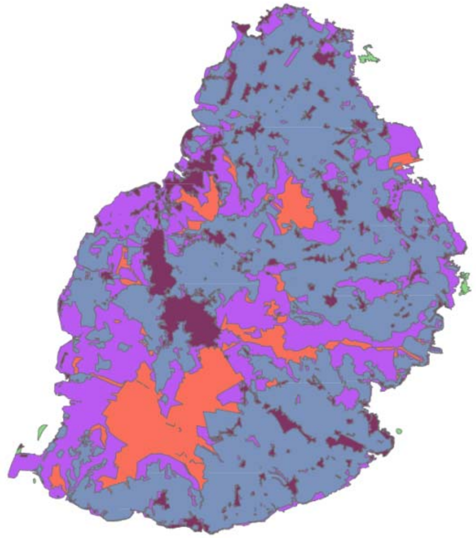


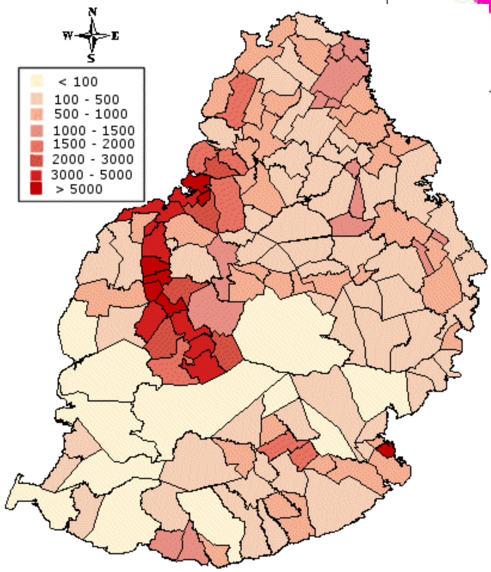


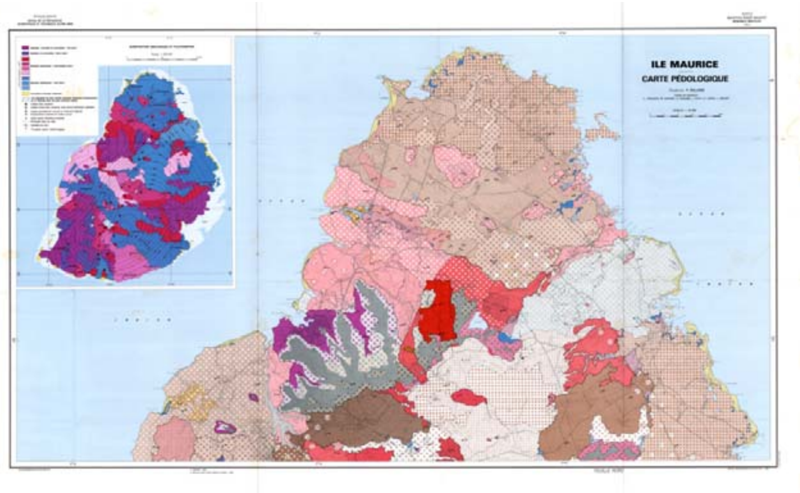
Input Maps used for AEZ



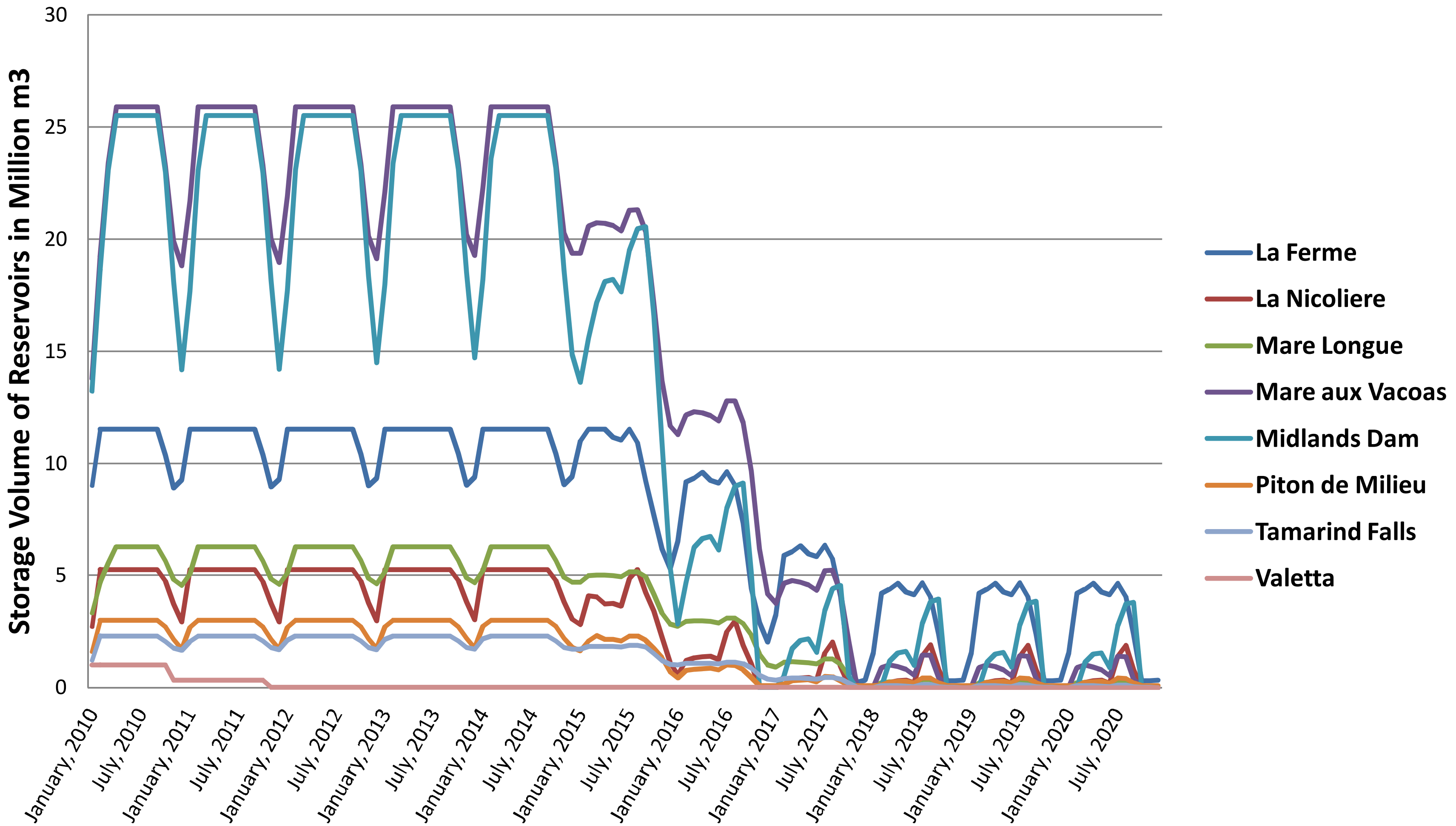








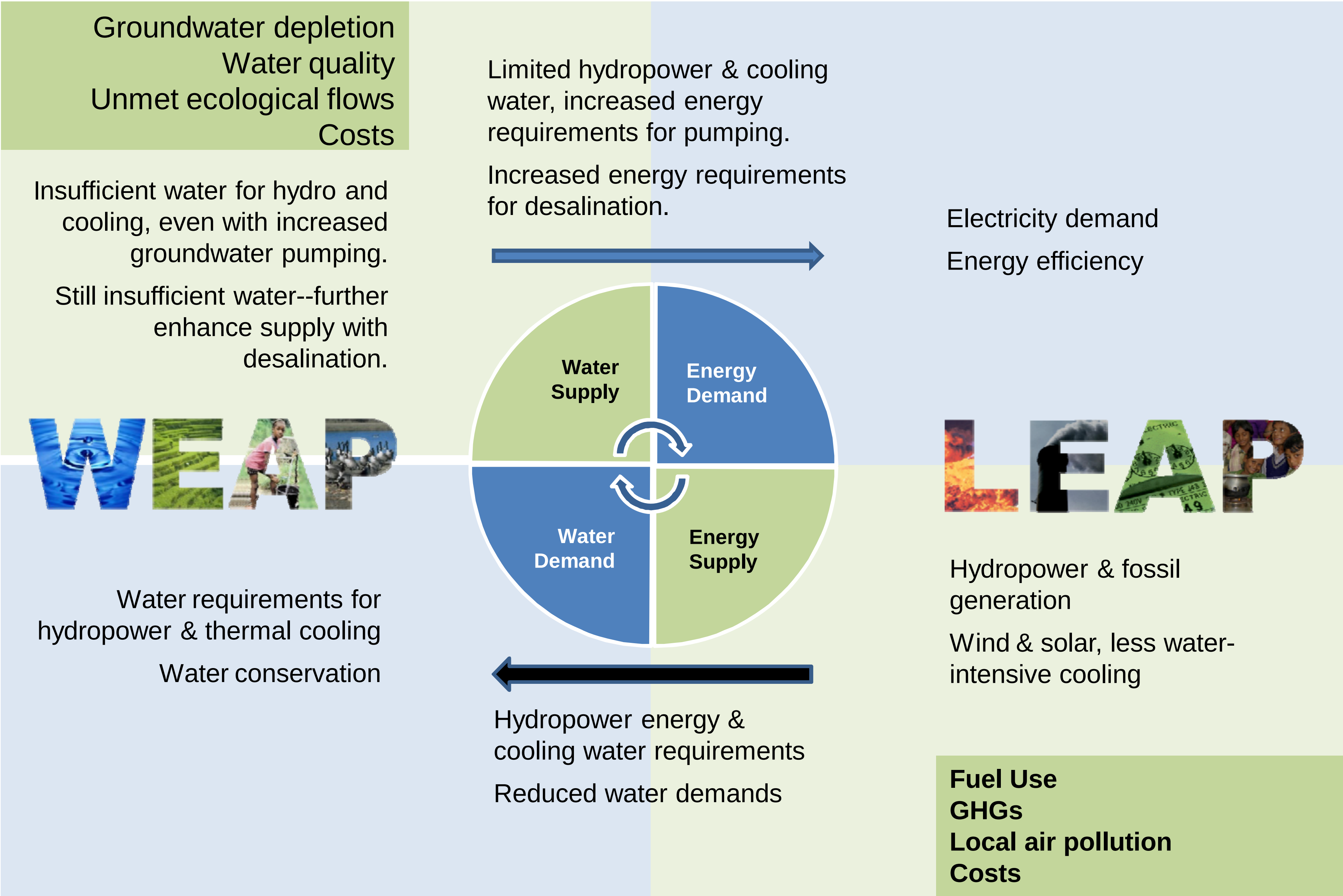
Results – Scenario B (40% rainfall reduction): Reservoir levels

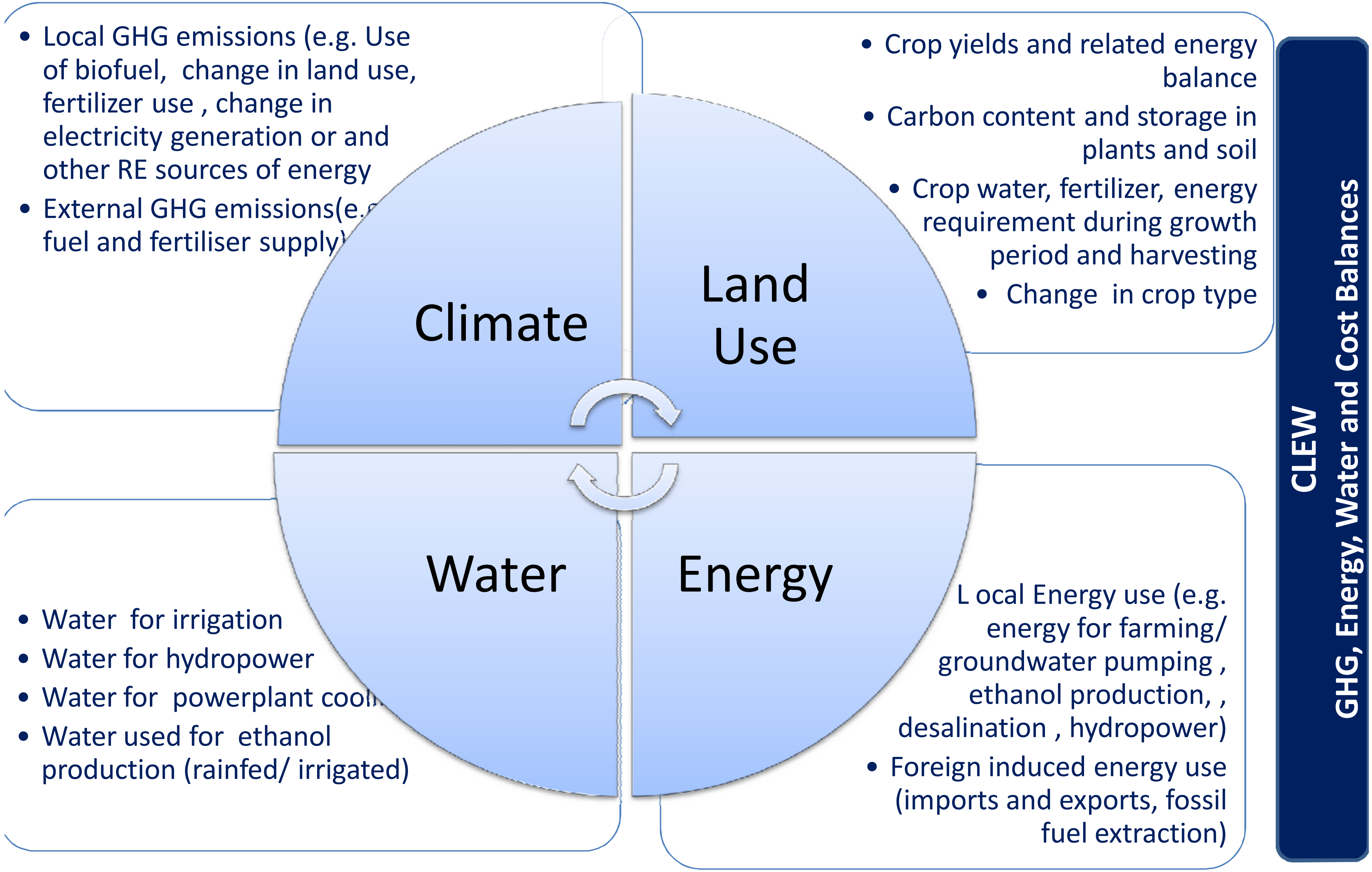


The elements modeled……

- **Local GHG emissions**
  1.Fertilizer use, farming emissions, change land-use
  2.Electricity production (coal substituting bagasse)
  3.Substitution of gasoline with ethanol
- **Foreign GHG emissions**
  1. Fertilizer production and transport 2. Indirect land use change
  3. Extraction and supply of coal 4.Extraction and refining of oil
- **Local energy:**
  1. Energy for farming,
  2. Electricity production/use (e.g. Pumping and distributing irrigation water) on site
  3. Petrol displaced by ethanol
- **Foreign energy**
  1. Fertilizer production and transport 2. Oil extraction and refining
  3. Coal extraction and transport for electricity production
- **Local fresh water use**
  1. Water applied for irrigation 2. Water used for ethanol/sugar processing
  3. Power station cooling
- **Crop land use for sugar cane**

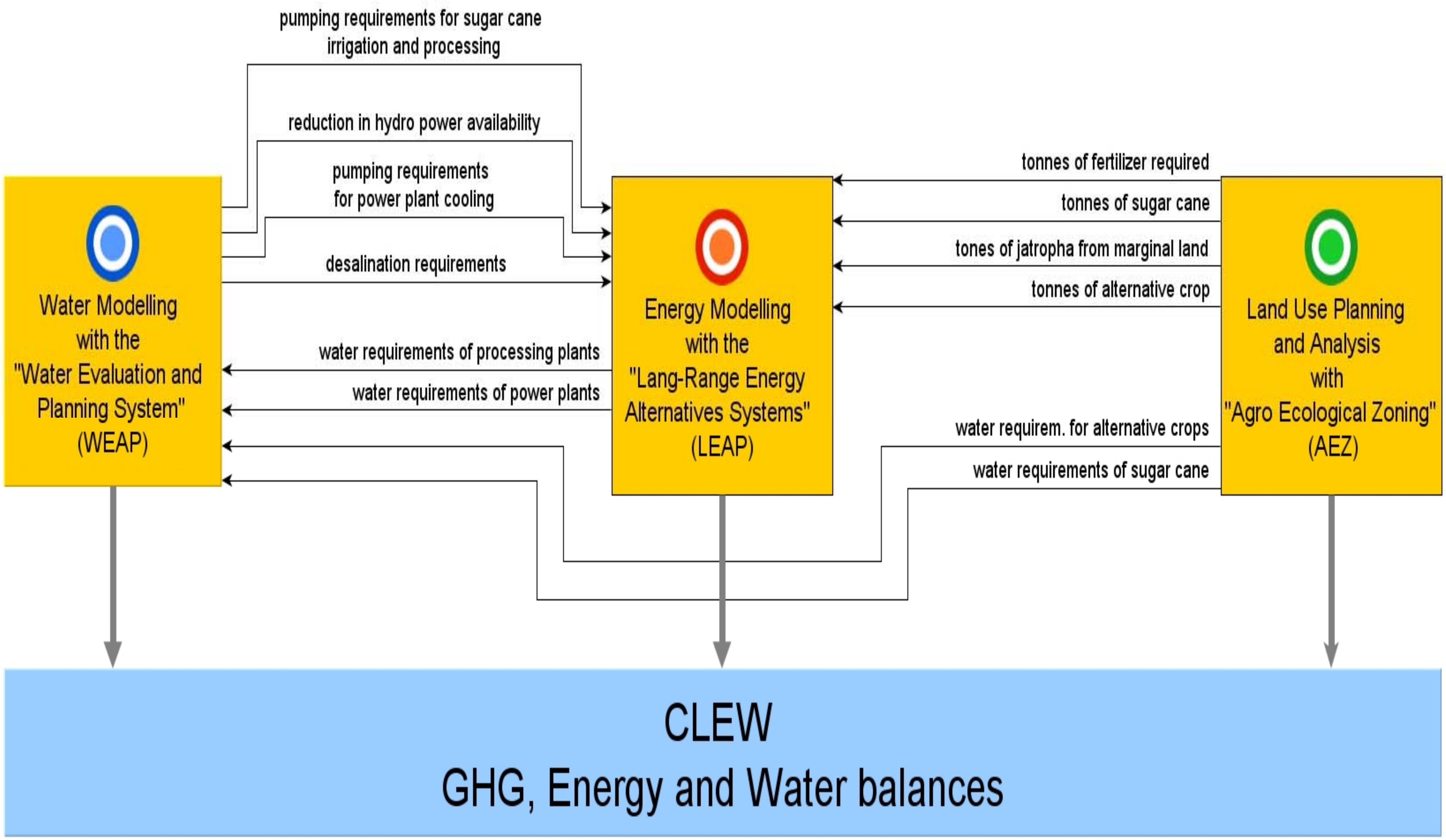
Linking Water and Energy Issues



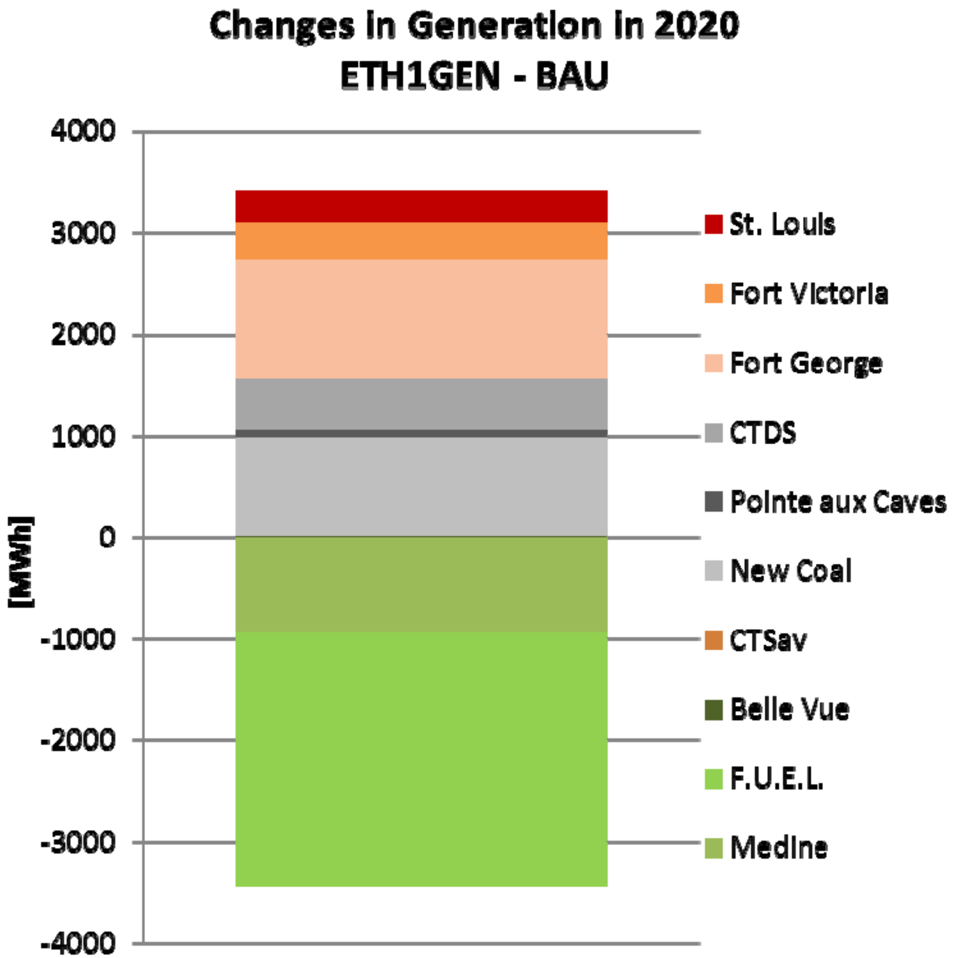


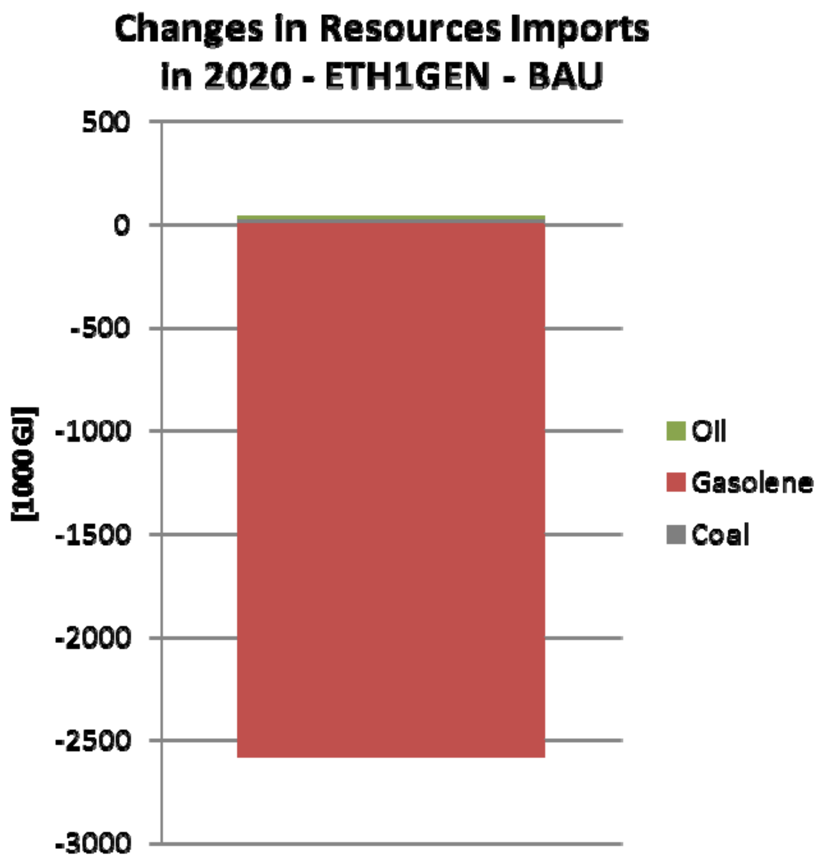
Local GHG emissions (e.g. Use of biofuel, change in land use, fertilizer use , change in electricity generation or and other RE sources of energy
External GHG emissions(e.g
fuel and fertiliser supply)
Crop yields and related energy balance
Carbon content and storage in plants and soil
Crop water, fertilizer, energy requirement during growth period and harvesting
Change in crop type
Climate
Land Use
Water
Energy
Water for irrigation
Water for hydropower
Water for powerplant cooli
Water used for ethanol production (rainfed/ irrigated)
L ocal Energy use (e.g. energy for farming/ groundwater pumping , ethanol production, , desalination , hydropower)
Foreign induced energy use (imports and exports, fossil fuel extraction)
CLEW
GHG, Energy, Water and Cost Balances

Model interactions



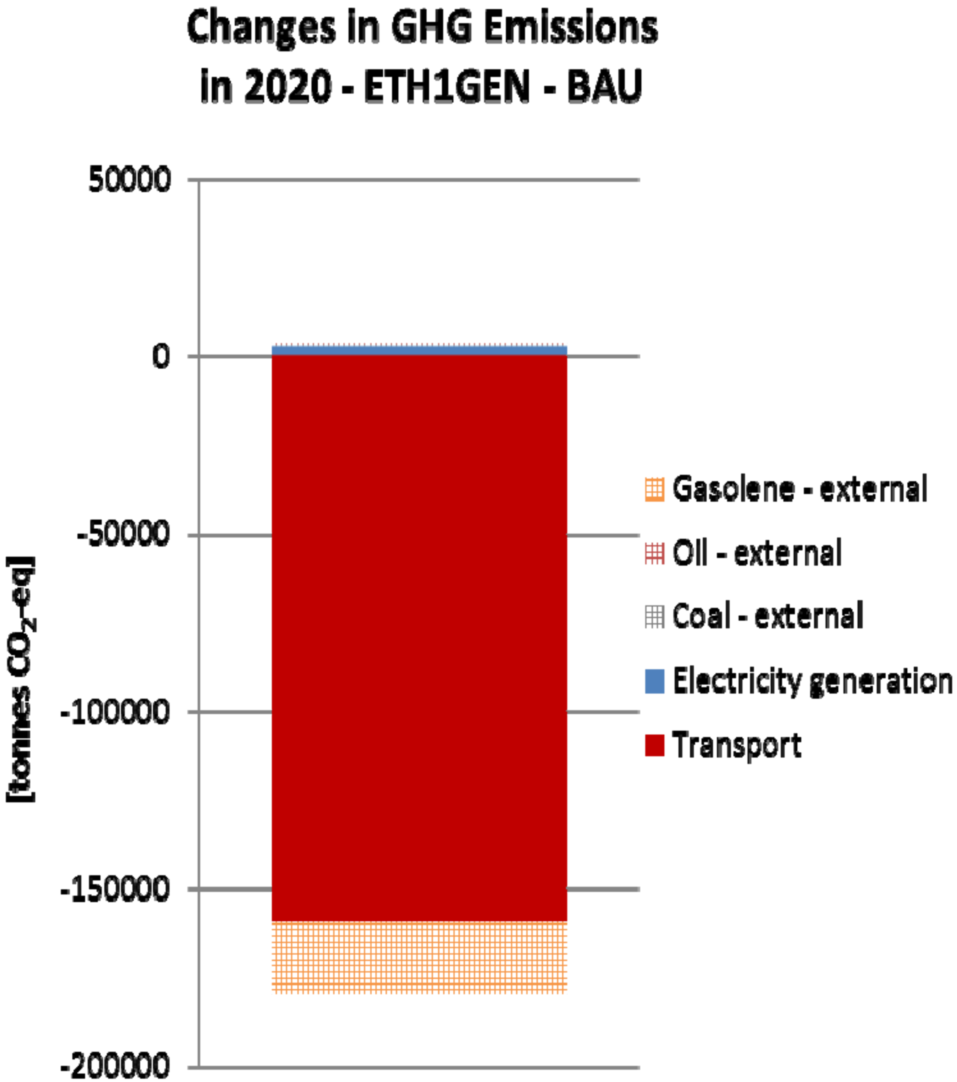
Results – Scenario1 -Without climate change (Ethanol 1st Gen.) - I

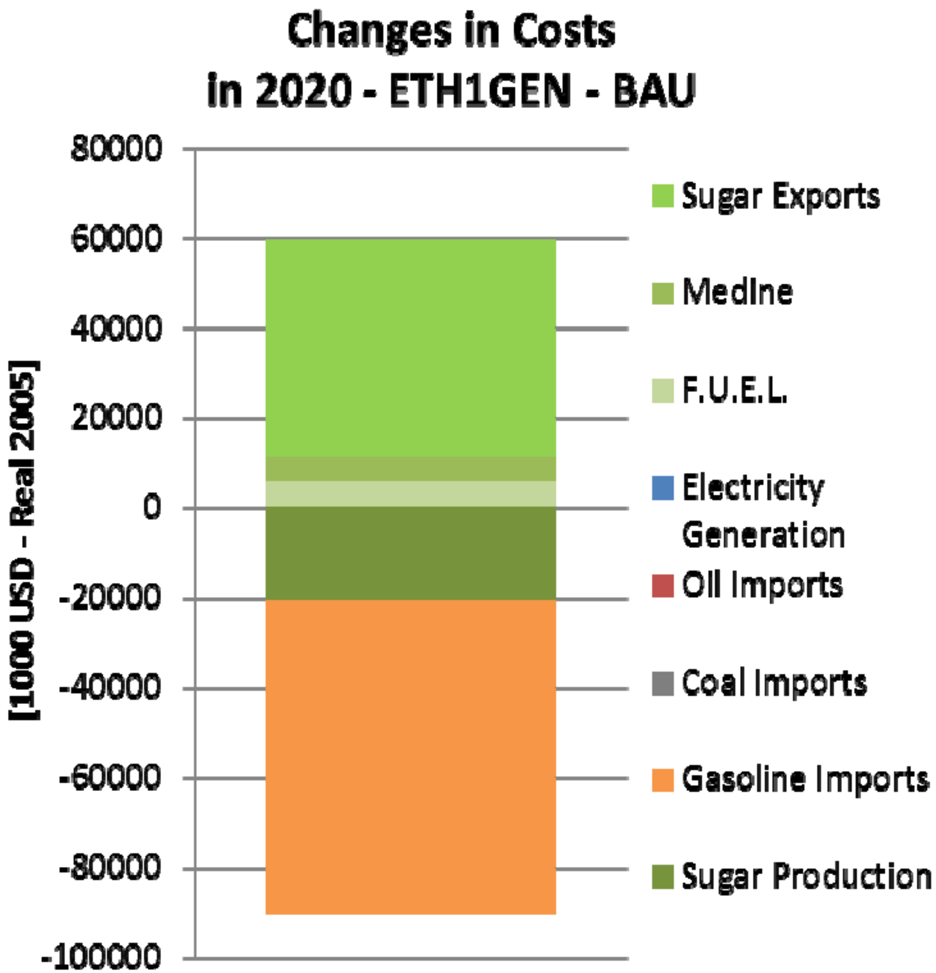




With increase in ethanol production, decrease in power generation by IPPs
Reduction gasoline imports

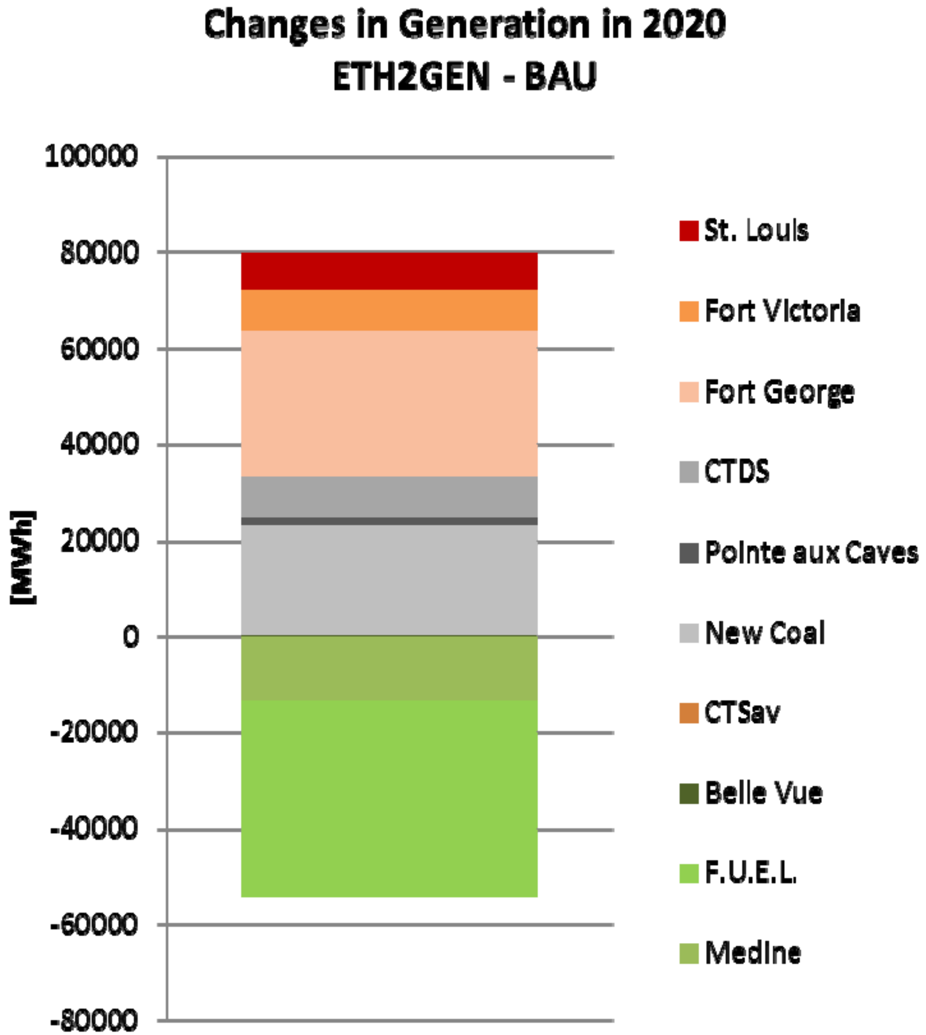
Results – Scenario 1 (Ethanol 1st Gen.) - II

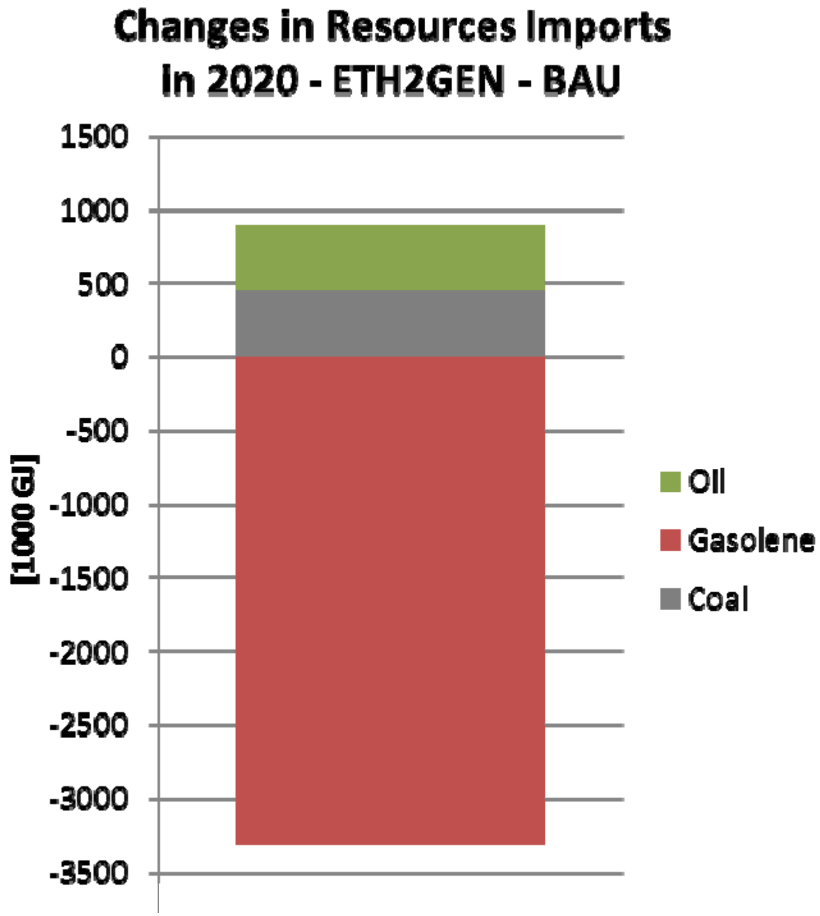




Significant reduction in GHG Emission (transport sector)/ saving on gasoline imports
Reduction in sugar production and sugar export

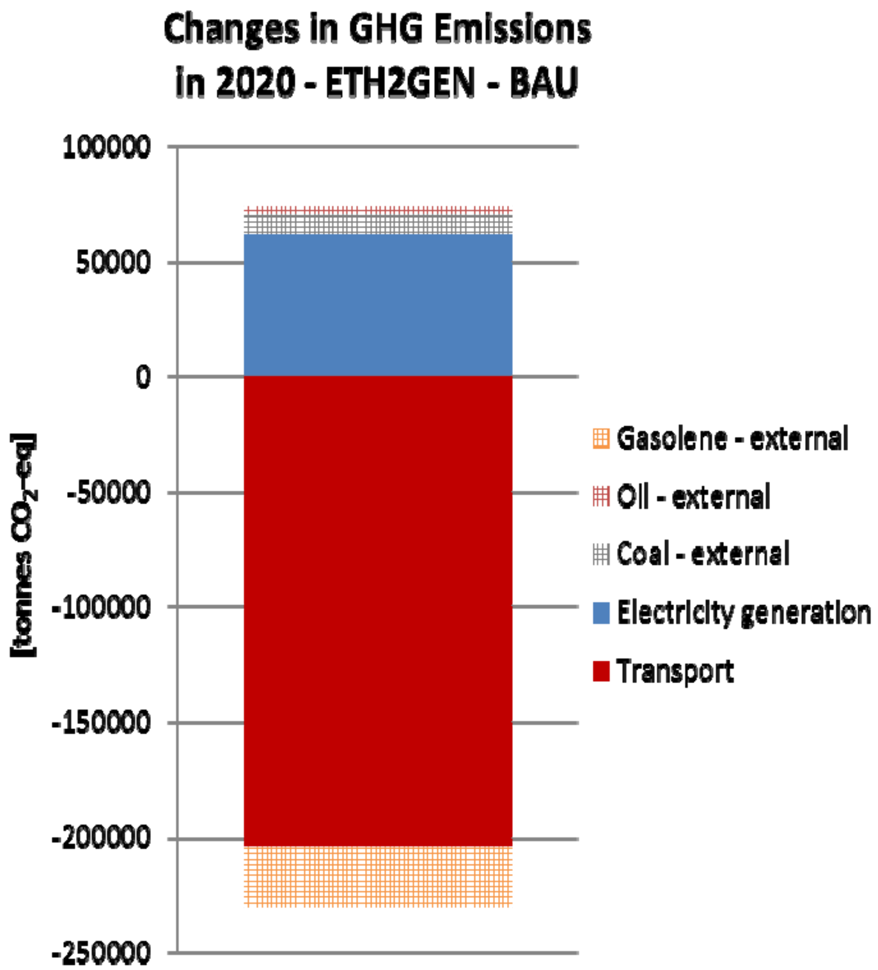
Results – Scenario 1 (Ethanol 2nd Gen.) – I

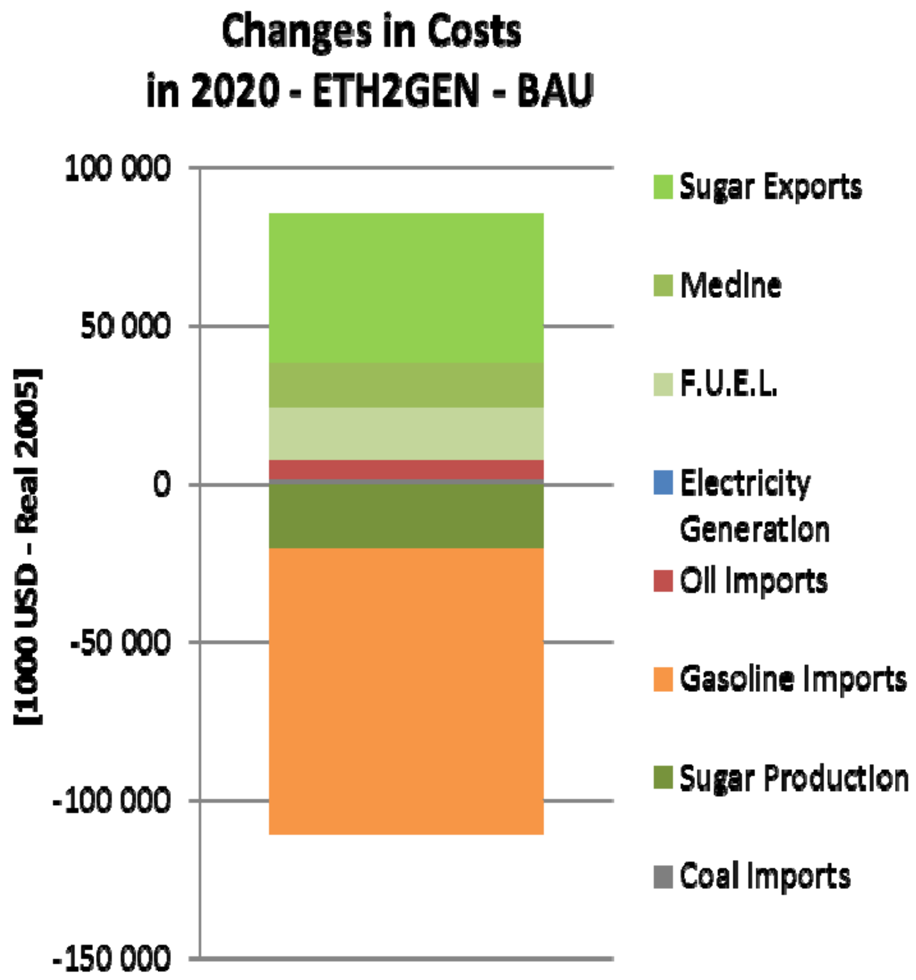




With bagasse being used for ethanol production , reduction in power generation by IPPs , increase in coal and oil imports to compensate for bagasse

Results – Scenario 1 (Ethanol 2nd Gen.) – II

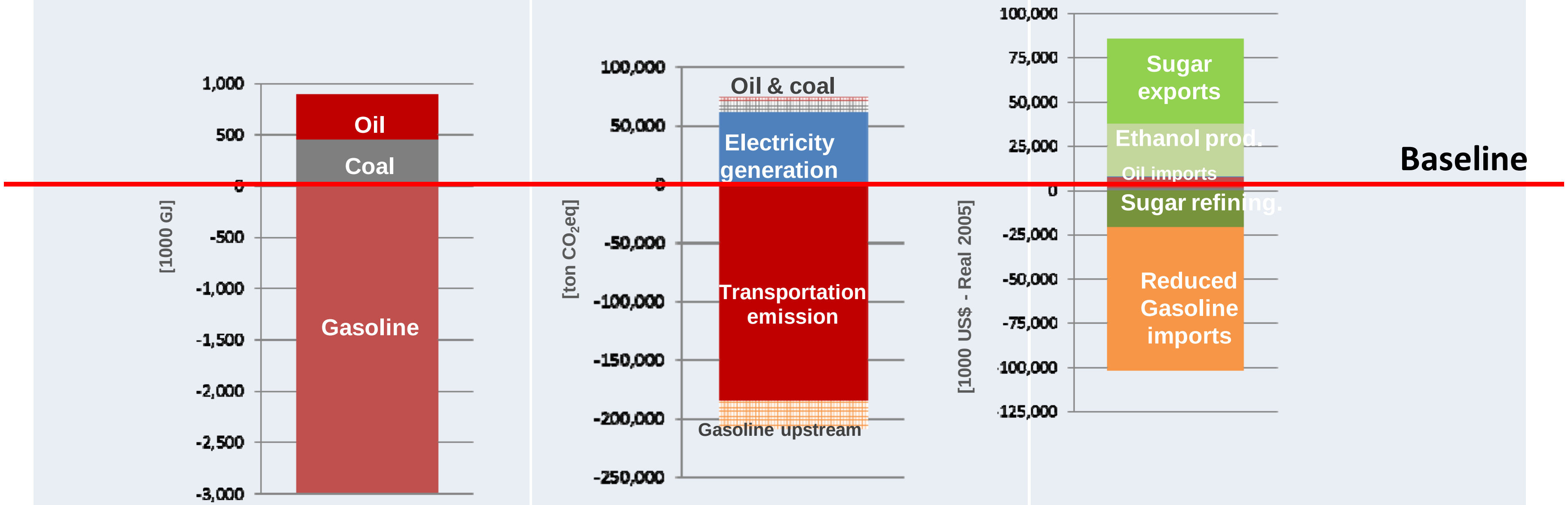




Reduction in GHG Emission (transport sector)/ saving on gasoline imports
Reduction in expenditure on sugar production and losses in sugar exports
Gen 2 ethanol - less attractive than Gen 1 ethanol in terms of profitability

THE IMPACT OF TRANSFORMING TWO SUGAR PROCESSING PLANTS TO PRODUCE 2nd GENERATION ETHANOL (PROJECTED FOR 2020)

Reduced fuel imports	Reduced greenhouse gas emissions	Reduced expenditures



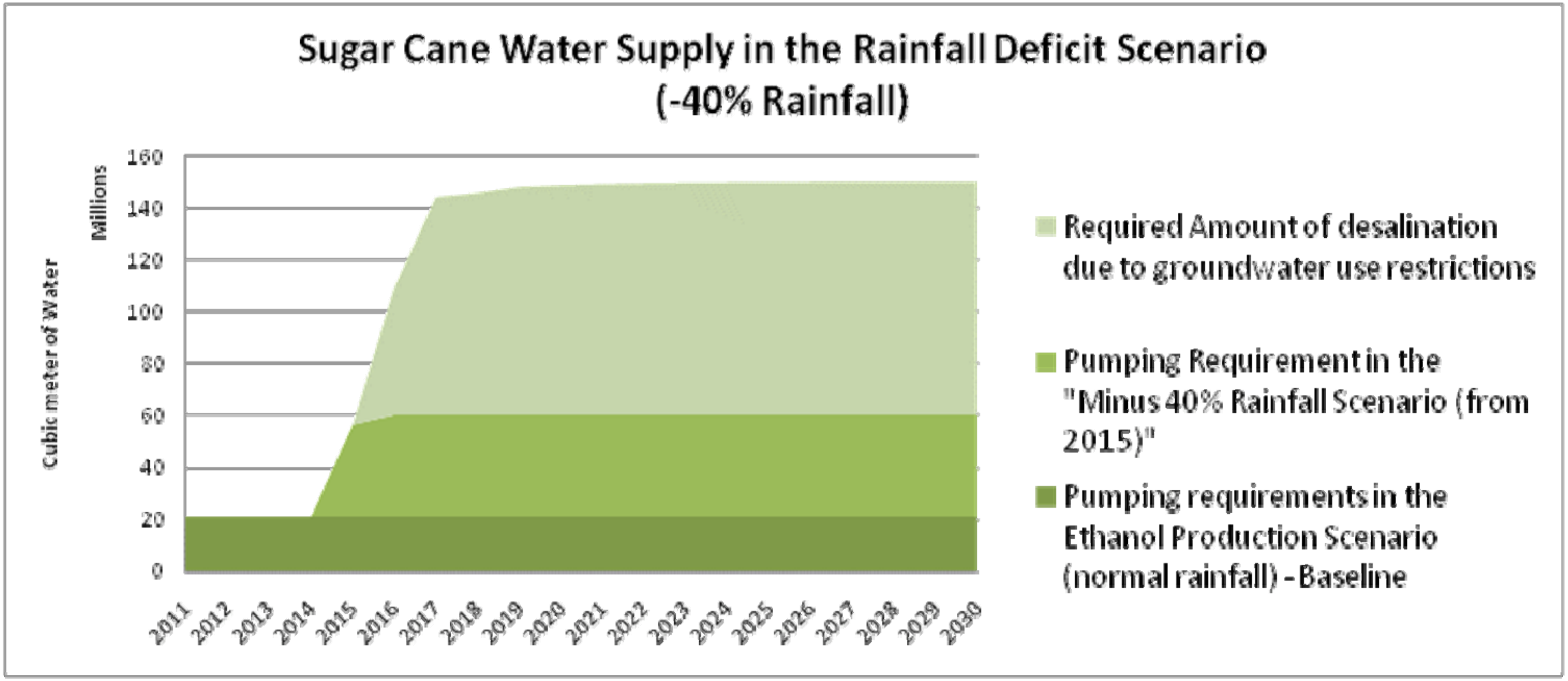
The import dependence decreases. Gasoline imports are reduced as ethanol replaces gasoline as a motor fuel. Some bagasse is diverted from electricity generation to ethanol production, which needs to be compensated for by increased imports of coal and distillate oil.

Total greenhouse gas emissions are reduced. upstream emissions are reduced as gasoline is replaced by ethanol. The increased use of coal and distillate oil (in place of bagasse) for electricity generation results in smaller additional emissions.

Ethanol production has an economic benefit. As some of the sugar is converted to ethanol, the expenditures for sugar refining and gasoline imports are reduced. This outweighs the reduced sugar export earnings and the costs associated with ethanol production and the increases in oil and coal imports.

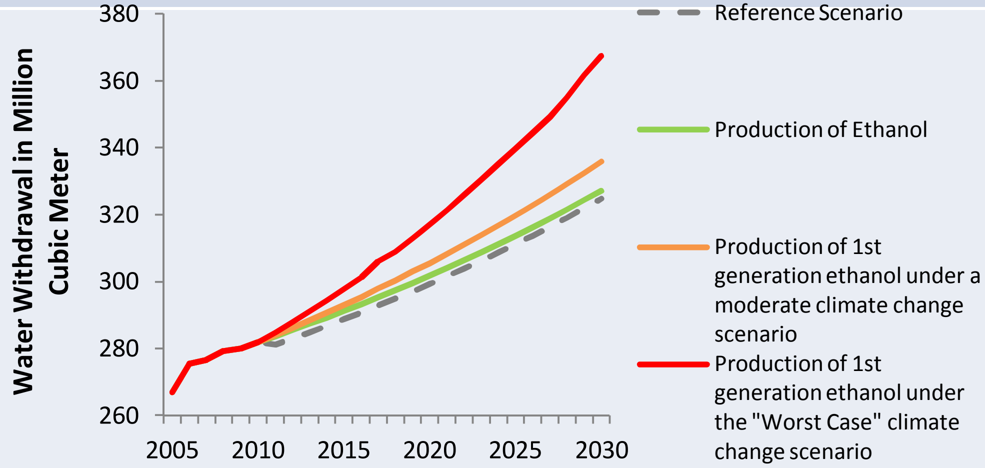
Results – Scenario 2 – with climate change (40% rainfall reduction): Increased pumping demand

- Desalination and pumping requirements



OVERALL WATER WITHDRAWALs AND ENERGY DEMAND IN DIFFERENT CLEW SCENARIOS

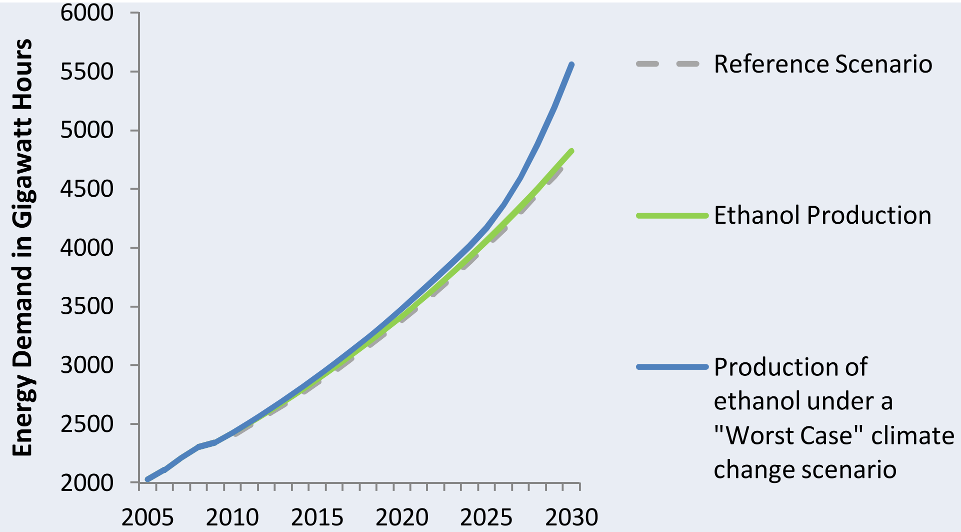
Mauritius Total Water Withdrawals Under Different Integrated CLEW Scenarios



Water withdrawals increase under climate change scenarios:

To compensate for reduced rainfall, irrigation will have to be expanded to previously rain-fed sugar plantations and farms. This leads to higher withdrawals. Of surface and ground water.

Mauritius Total Energy Demand Under Different Integrated CLEW Scenarios



Increasing Energy demand for biofuel production:

Energy demand increases as demand for water pumping and desalination grows to meet demand as rainfall is reduced. .

Results – Scenario 2 : BAU, sugar production under water stress conditions Ethanol 1st Gen under water stress conditions

Under current conditions, a decline in rainfall will result in

- -considerable reduction in hydropower generation
- -reduction in sugarcane/ bagasse production

thus affecting total electricity generation.

Increased irrigation water demand

↓

Increased withdrawal from reservoirs for urban and agricultural water demand, thus leaving little water for hydropower generation

↓

Increasing need to abstract water (pumping) from underground sources and desalination to meet water demand

↓

thus requiring additional electricity demand

↓

met by oil-fired and coal power generation

↓

leading to increase in GHG emission

Results – Scenario 2 (with climate change)
New drought tolerant biofuel feedstock crop under water stress conditions

Agro-ecological zones methodology was used for assessment of agro-ecological assessment of a range of bio-fuel crops (cassava, jatropha, miscanthus, maize) with their characteristic fertiliser, water and energy demand and GHG emission.

Crop suitability of under rain-fed and irrigated conditions for current and future projected climate (GCM model EHA22050) showing strong decline in rainfall and length of growing period.

The total energy produced by sugar cane from both sugar (ethanol)and bagasse (electrical power) would be highest than any of the other feedstock options assessed for the same cultivated rain-fed and irrigated land

	Oil equivalent (Ktoe)	
Sugar cane (sugar) Sugar cane (bagasse)	237 – 245 295 – 304	532-550
Cassava (root)	137 – 141	
Maize (grain)	127 – 141	
Miscanthus (agb)	252 – 260	
Jatropha (oil)	187 - 200	

Sugar cane is the most effective feedstock for bio-energy to increase energy security in Mauritius

However, expansion of irrigated areas is necessary to sustain high yield under climate change

KEY FINDINGS OF CLEW APPLICATION IN MAURITIUS (1)

Faced with the challenge to water, energy and food security, the CLEW approach enables integrated analysis for multi-resource planning &in assessment of different scenarios in the planning for a green economy

Scenarios	Main Findings	Overall impact
BAU- sugar production with effort to meet crop water requirement (water stress)	Reduction in hydropower Increase in fuel import for electricity production Increase in water demand for irrigation	Need to investigate other water sources and increase in ground water pumping while avoiding sea water intrusion in aquifers
Changing sugar production to **ethanol production (Gen 1**) (water stress)	Reduced gasoline import & significant reduction in GHG emission Income diversification Change in process require slightly more electricity and water	Increase energy security Positive economic balance due to gains from reduced gasoline imports but need to consider cost of shifting from sugar to ethanol production/

KEY FINDINGS OF CLEW APPLICATION IN MAURITIUS (2)

Scenarios	Main Findings	Overall impacts
- Sugarcane and hydrolysis of bagasse to **ethanol production (Gen 2)** (water stress)	Significant reduction in imported gasoline Slight increase in GHG Emission due to more coal being burned for electricity production	Economically less favourable due to increased cost of power station fuel
Sifting from sugarcane to alternative drought tolerant biofuel crops (water stress)	Less water demand. Lower energy demand for desalination and pumping. More coal required for power production Lower ethanol yield at a higher cost than sugarcane, but better for the Island's GHG balance	Overall cost benefit balance less favourable Sugar cane best yield and bio-energy crop but more water required to sustain yield under future projected climate

Conclusion

The CLEW case study has helped to

- Develop and calibrate energy, water and land-use model for Mauritius under decreasing rainfall over long term period
- Demonstrate the integrated analysis of the resources and their interactions with climate is possible to quantify
  - GHG emissions
  - Cost associated to meet energy, water and food security goal

- Enable a more holistic assessment of GHG emissions (including external effects)
- Analyse and compare the impacts of **different policy options/ scenarios** and thus provide an insights into the implications of
  - moving food production (sugar) to fuel (biofuel)

    Ethanol (Gen 1) production is lower cost and better for the island's GHG balance than sugar production under current assumptions
  - Shifting to alternative bio-energy crop on energy secuity

    New crops evaluated produces less ethanol at a higher cost than sugarcane, but better for the Island's GHG balance

- Provided an opportunity to concurrently assess and quantify implications of
  - mitigation (shift to bio-ethanol) for energy security and
  - adaptation (desalination) measures for water security

Benefits of the Case Study

The national CLEW case study has

- Provided a better understanding of the attributes of the CLEW systems and their inter-linkages and potential
- Created awareness on how to address complex issues such as interactions and strong inter-linkages in CLEW systems for efficient resource planning and decision making
- Changed the traditional way of thinking (sectoral approach to system thinking /integrated approacch to address tool and coordinated efforts from different stakeholders
- Provided an understanding of the technical skills, tools and data required for cross-sectoral medium and long term policy planning
- Created awareness of the need to
  - build research and institutional capacity in the use modelling tool to address CLEW resources and for integrated policy planning
  - promotes collaboration of experts from different sectors in assessment of resource related stresses.

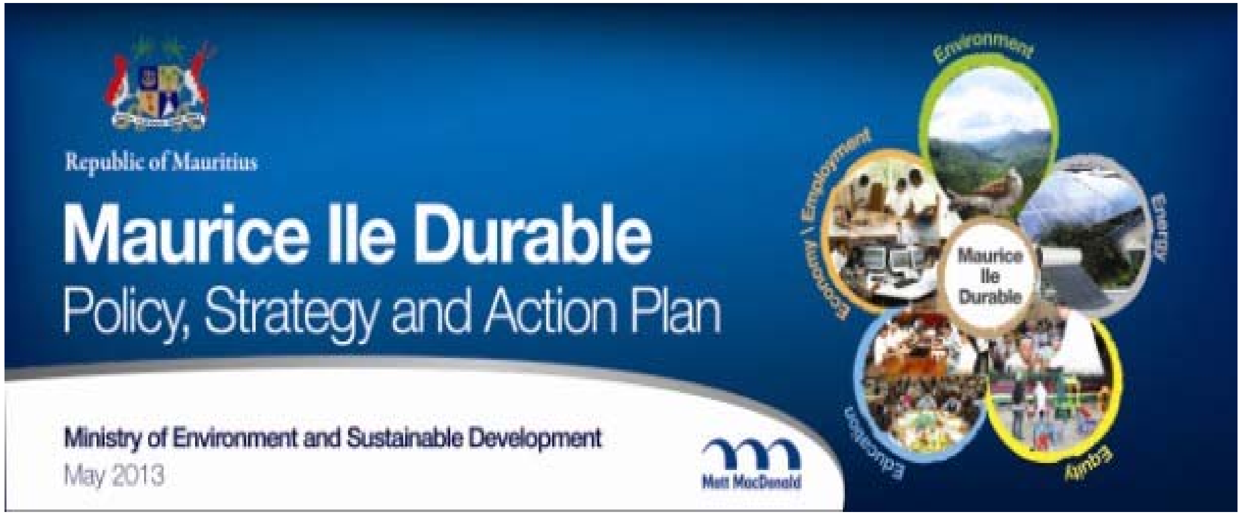
Future work
using the CLEW framework

- Much closer look at seasonality, water storage and intermittency
- Develop an optimization framework to determine 'unpredictable' outcome
- Investigate on the implications of new scenarios
  - water and energy efficiency options
  - use of low -carbon electricity generation(solar or wind) for desalination and water transfer uplands to meet increasing water demand
  - Use of compost to increase yield, soil C sequestration and improve water balance
  - Substituting coal by biomass (*Arundo donax actually under experimentation)*
  - Land use change due to urbanisation (provided acquisition of satellite data)
  - Change in global market price of fuel.





THANK YOU



Making Mauritius a sustainable island focussing on

Reducing dependence of fossil fuel and reducing GHG emission …

Improve energy efficiency and conservation in all sectors through demand-side management measures (gains of 10% by 2025)

Guiding Principles

- **Promote adoption of integrated holistic approach to decision-making**
- **Promotion of a climate resilient development pathway**

-Ensuring that climate change issue is considered in land-use planning and strategic environmental impact assessments and adaptation strategies

- To build capacity in the use of integrated modelling tool to analyse the inter-linkages between climate change and key resources such as land-use, energy and water to promote integrated approach for detailed resource assessment

Other Policies Underway

Renewable energy master plan (under preparation)

Water Master Plan : for the development of water resources in Mauritius (2025-2050) (just completed)

- **Mobilisation of additional water resources** through construction of new dams or enlargement of existing dams, installation of pumping stations on rivers, new boreholes, reducing network losses and reviewing the water rights legislation for allocation of permits for a more equitable distribution.

- **Institutional reform** for effective management of water resources
- **Prevention of surface and groundwater pollution**,
- **Promotion of sustainable watershed management**,
- **Reduction of unaccounted-for-water to 25% by2030**
- **Optimising reuse of treated wastewa**ter