The technology selection analysis based on bi-level environoeconomic optimization of a biomass-powered CHP system

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Presentation Contents

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Why biomass-fueled energy systems?

Countries have changed their energy policies towards smart systems because:

1. Global greenhouse gas (GHG) propagation
2. Climate change

Smart energy system is a holistic and cross-sectoral energy system.

100% renewable energy systems
Storage synergies across energy subsectors
Exploit low-value energy sources such as biomass

https://siteselection.com/theEnergyReport/2014/mar/guelph.cfm

Optimization necessity

- **Biomass has its <u>advantages</u> compared to other hydrocarbon energy resources**
  - can be called CO^2-neutral
  - low or zero purchase cost
  - Largely dispersed around the world
- **It has its own <u>disadvantages</u>**
  - Seasonality of feedstocks
  - Storage problems

Biomass-fueled systems complexity

- **Modeling Complexity**
  - Numerous Parameters
  - Multiple objectives
- **Operation Uncertainty**
  - Feedstock Supply
  - Energy Demand Variation
- **Decision Making Multiplicity**
  - Operating parameter (energy generation, utilization time)
  - Performance parameters (cost, pollution, renewable usage rate)

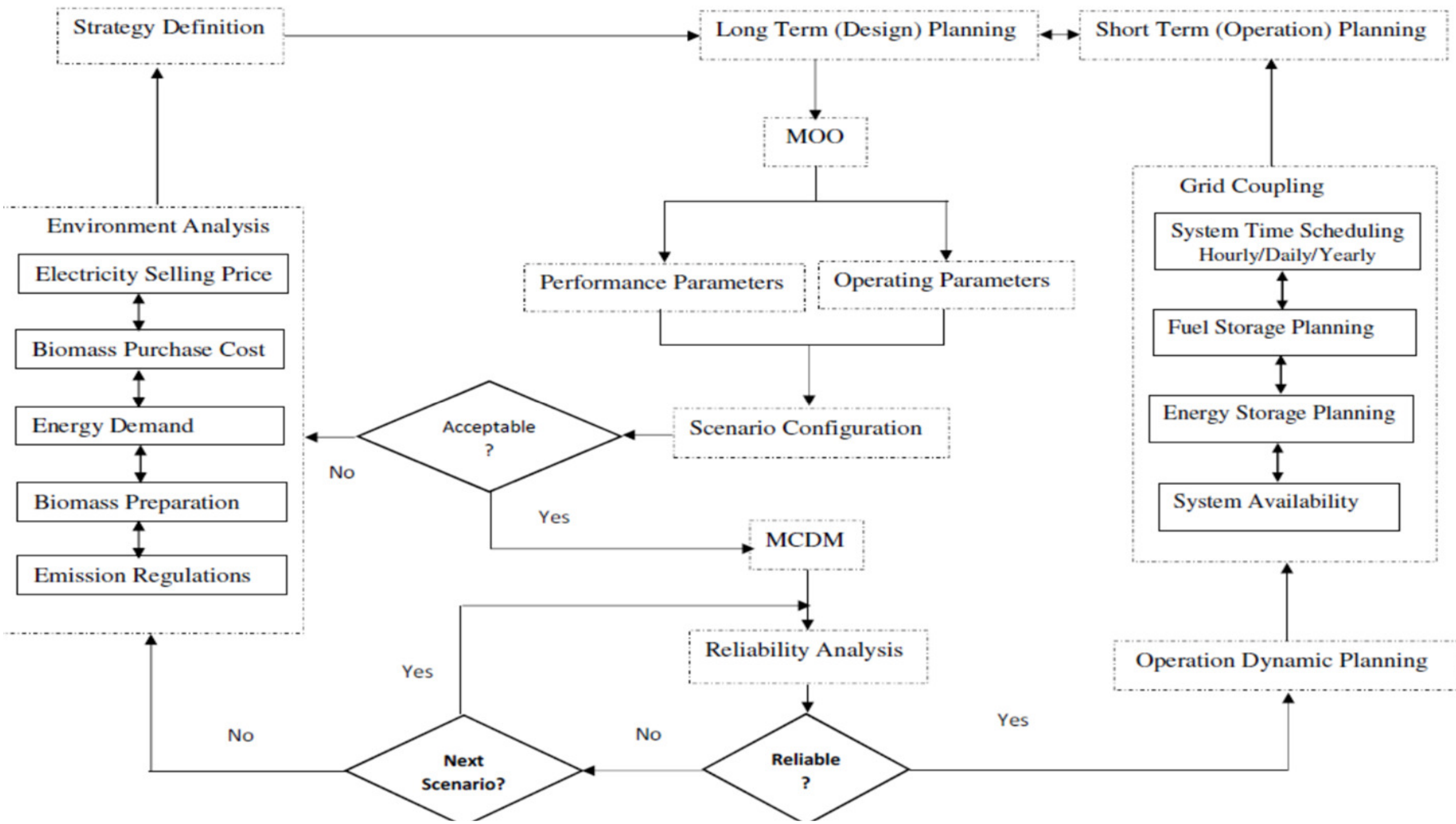
Overview

- Scenario definition based on the used technologies and fuels (Canada)
- Energy generation (heat and electricity modeling) modeling
- Bi-level Multiple Criteria Decision Making and Multiple Objective Optimization MCDM-MOO method for optimization
- Explicit nonlinear environoeconomic optimization approach

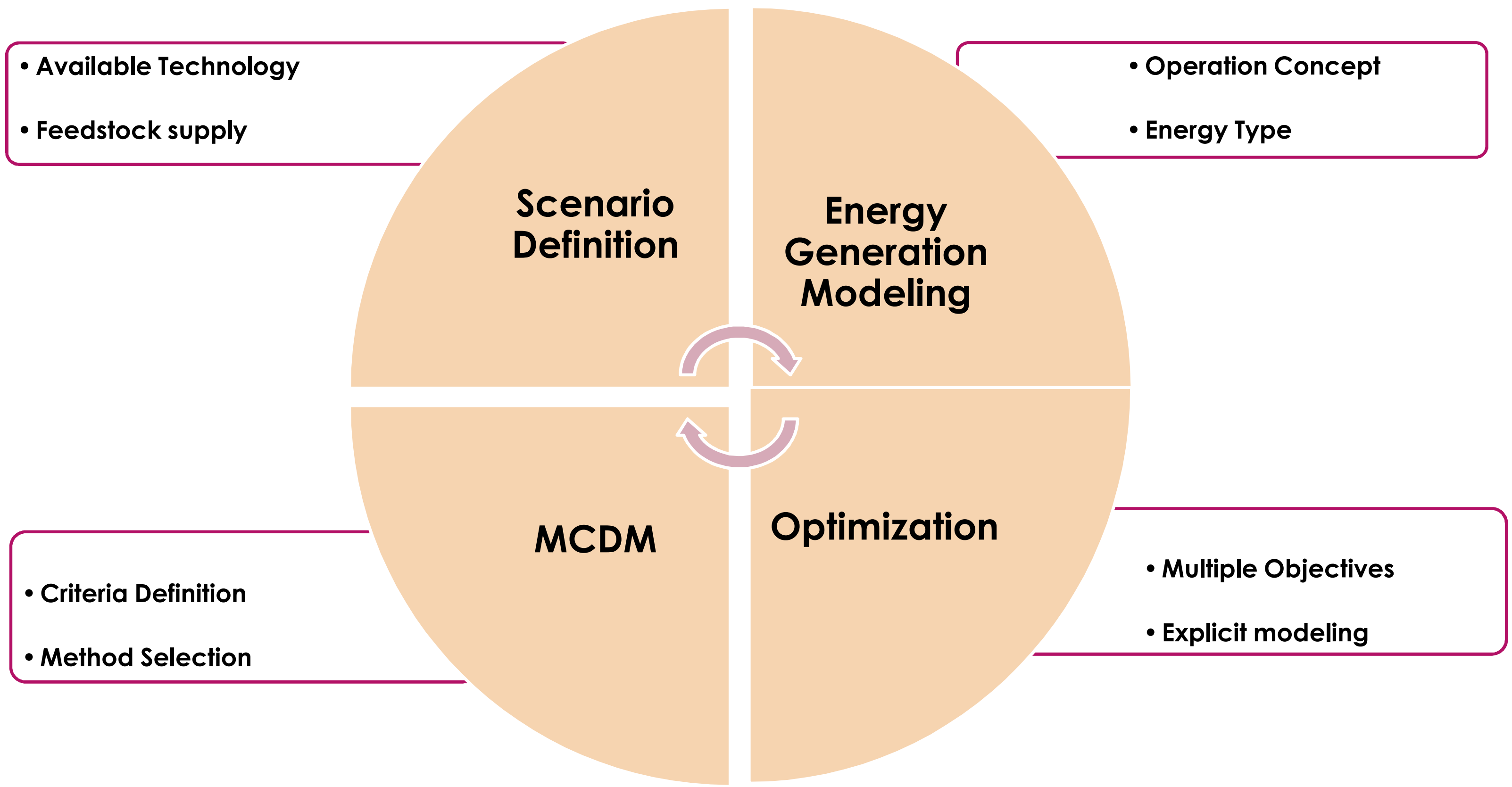
To deliver

- Scenarios optimized operating and performance values
- Scenario ranking for covering uncertainty

Methodology-Environoeconomic Optimization



Methodology Bi-level Optimization



MCDM Criteria

Operating Parameters

1. Electrical Capacity (kw) → Max
2. Thermal Capacity (kw) → Max
3. Utilization Time for electricity generation (hour) → Min
4. Utilization Time for thermal generation (hour) → Min
5. Electricity Efficiency → Min
6. Thermal Efficiency → Min
7. Electricity purchase rate ($/Kwh) → Min

Performance Parameters

Minimum of

1. Initial Investment Cost
2. Biomass Fuel Cost
3. CO_2 emissions
4. SO_2 emission

Analytical MODELING- Cost

Life Cycle Cost Approach (LCC)- Net Present Value (NPV) method

Annualized Capital Cost= $\frac{(C*\emptyset+U_{fix})}{P_{i,th}*\tau_{th}}+\frac{y_f}{\eta_{th}}+U_{var}-(y_{el})\frac{P_{el}\tau_{el}}{P_{th}\tau_{th}}$

annuity factor: $\emptyset=\frac{d}{1-(1+d)^{-N}}$

Fuel cost: $y_f=\frac{(Price\ Per\ Ton)*(\tau_{th}*P_{th}+\tau_{el}*P_{el})}{(\eta_{el}+\eta_{th})}$

y_{el}= Electricity selling price to grid

K. Sartor, S. Quoilin, P. Dewallef, Journal of Applied Energy 130 (2014).

Analytical MODELING- Emission

$$m_{co2} = \frac{\left((\mathrm{P_{el}} * \tau_{el}) + (\mathrm{P_{th}} * \tau_{th})\right) * 44 * \text{Biomass Carbon Mass Fraction}}{(\eta_{el} + \eta_{th}) * 3.6 * \mathrm{NHV}}$$

$$m_{So2} = \frac{\left((\mathrm{P_{el}} * \tau_{el}) + (\mathrm{P_{th}} * \tau_{th})\right) * 64 * \text{Biomass Sulfur Mass Fraction}}{(\eta_{el} + \eta_{th}) * 3.6 * \mathrm{NHV}}$$

NHV = Net Heating values

NHV= (34.1C+101.98H-9.85O+6.3N+19.1S)*(1-MCWB/100)-0.02452*MCWB

K. Sartor, S. Quoilin, P. Dewallef, Simulation and optimization of a CHP biomass plant and district heating network, Applied Energy 130 (2014) 474–483
Vallios.I, Tsoutsos.T, Papadakis.G, Design of biomass district heating systems, Biomass and bioenergy 33 PP. 659-678. 2009

Scenario Description

- **40 different scenarios combined of eight fuels and five technologies**

Index	Fuel Type	Index	Technology	
F_1	Bagasse	T_1	Boiler	Heat Only
F_2	Pit	T_2	Boiler+ Gas Turbine	CHP
F_3	Rice husks	T_3	Boiler+ Steam Turbine	
F_4	Switch grass	T_4	Boiler+ Steam Turbine+ Gas Turbine	
F_5	Wheat straw	T_5	Boiler + Internal Combustion Engine (ICE)	
F_6	HHV wood			
F_7	MHV wood			
F_8	LHV wood			

M. Rivarolo, A. Greco, A.F. Massardo, Thermo-economic optimization of the impact of renewable generators on poly-generation smart-grids including hot thermal storage, Energy Conversion Management 65 (2013)

RESULTS ANALYSIS - First level optimization

40 scenarios optimal results (7 operating and 4 performance parameters)

	Cost (CAD/kWh)		Emission (Ton)		kW		Hour		Efficiency		CAD/kWh	CAD/kWh
	Investment	Fuel	Co_2	So_2	P_{el}	P_{th}	τ_{el}	τ_{th}	η_{el}	η_{th}	Y_{el}	Final cost
F3T1	0.0002	0.0049	7,806,887	14,622.0	0.00	7,440	0	7,905	0.00	0.69	0.00	0.0051
F3T2	0.0178	0.0042	0.1	0.0	0.00	0.00	3,801	8,537	0.20	0.60	0.11	0.132
F3T3	0.1858	0.0042	320,463.9	600.2	445.94	1.43	6,214	7,664	0.25	0.55	0.20	0.0184
F3T4	0.1712	0.0038	302,046.9	565.7	496.92	3.04	5,903	6,685	0.40	0.50	0.20	0.0326
F3T5	0.1254	0.0042	190.6	0	0.76	0.00	2,162	6,600	0.30	0.50	0.20	0.0788

Second Level Analysis - Scenario Ranking

Optimized values of the objectives and operating parameters for top scenarios

	Final Cost (CAD/kwh)	Co2 (ton)	So2 (ton)	P_{el} τ_{el} (mWh)	P_{th} τ_{th} (kwh)	Y_{el} (CAD/kwh)
F1T4	0.0324	36,437	4,359	442	4,636	0.176
F2T4	0.0532	144,040	10,800	2,289	149,361	0.168
F3T3	0.0184	320,463	600.2	8.9	10,960	0.20
F4T3	0.021	680,539	166,890	7,175	99,678	0.19
F5T4	0.0264	207,776	1,223	2,478	9,545	0.20
F6T2	0.037	98,942	0	670	16,518	0.20
F7T3	0.029	108,118	0	1,666	15,272	0.19
F8T3	0.025	708,975	126,660	11,921	573,556	0.187

Sensitivity Analysis- Electricity selling price rise up to 0.15 CAD/kWh

	Final Cost (CAD/kWh)	Co2 (ton)	So2 (ton)	$P_{el}\ \tau_{el}$ (mWh)	$P_{th}\ \tau_{th}$ (mWh)	Purchase cost (CAD/ton)	Annuity Factor
F1T2	0.014	99894	11949	10.95	0.00	0	0.035
F2T2	0.08	5894	442	876.39	24.99	0.1	0.020
F3T3	0.006	903840	169286	7,675	17.07	0.2	0.041
F4T3	0.003	551840	135330	5,839.91	17.97	0.1	0.023
F5T2	0.007	1109839	65315	11,678.76	165.98	0.2	0.020
F6T3	0.002	801268	0	9,132.26	2.26	0.30	0.025
F7T3	0.003	1380709	0	19,322.51	102.78	0.25	0.023
F8T2	0.006	803295	143512	8.77	0.00	0.20	0.021

DISCUSSION

- System Scale has high sensitivity to
  - Biomass purchase price
  - Electricity selling price
- Increasing electricity selling price does not necessarily means the higher electricity to heat ratios
  - Higher costs (more biomass and lower electricity efficiencies)
  - Higher pollution
- Lower electricity selling price in CHP concept is more inclined to gas turbine cycles
  - Gasification for medium and high heat content biomass
  - Combined Cycles Shows better performance for CHP concept
  - Rankine Cycles are better fit for lower cost energy generation.

Conclusion

- Flexibility of the model to accept various fuels and technologies
- Capability of the model to accept hierarchical structure for approache integration
- Multiplicity of the parameters covering

Thank You