Eficiencia Energética: El Gigante Dormido

Cristian Cárdenas-Lailhacar

Dept. of Indusntrial and Systems Engineering
University of Florida
303 Weil Hall, P.O. Box 116595
Gainesville, FL 32611

PUCV – Biogas Conference - Valparaiso - CHILE

GREETINGS

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Outline

- Energia y Medio Ambiente
- Donde Estamos ? **BIOGAS – One Way**
- Energia: Un Indicador de Desarrollo ?
- Desafios para el Progreso
- Educacion e Investigacion en Chile ?
- Integracion ?
- Academia - Industria: Algunos Ejemplos

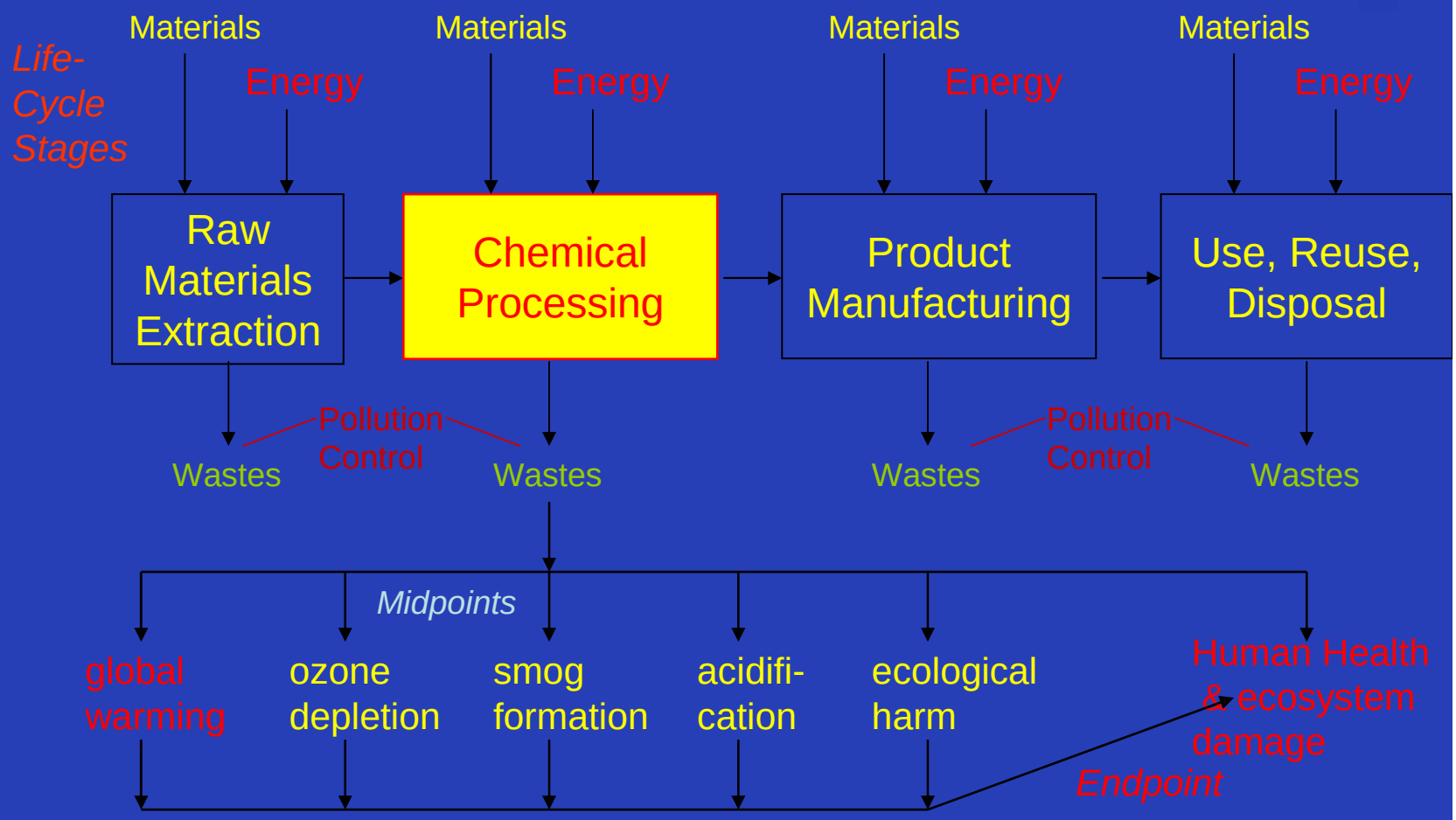
CONSUMO MUNDIAL DE ENERGIA

Cambio Porcentual Anual en Consumo de Energia (10^{15}BTU)

Energy Source	1970	1990	2010	1970-1990	1990-2010
Oil	97,8	135,4	181,3	1,6	1,5
Natural Gas	36,1	72,0	106,8	3,5	2,0
Coal	59,7	91,9	118,0	2,2	1,3
Nuclear	0,9	20,3	24,4	16,9	0,9
Renewables	12,2	26,2	41,1	3,9	2,3
TOTALS	**206,7**	**345,6**	**471,7**	**2,6**	**1,6**

Environmental Impact

(Reproduced with permission from EPA Green Engineering)



Medio Ambiente

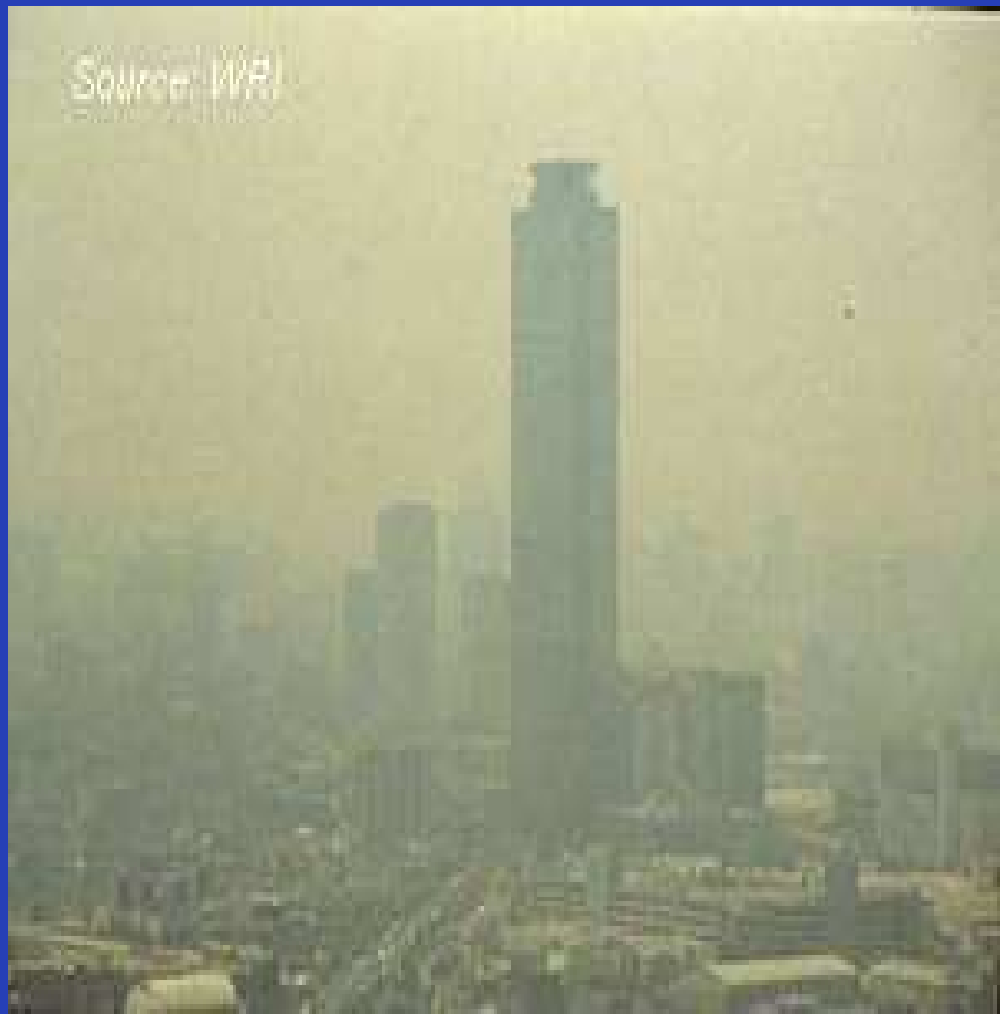
- **Pollution: biggest factor impact in**
  - Urban development and increased industrialization
  - Vehicle emissions and stationary source-fuel combustion.
- **Health issues**
  - Sulfur dioxide
  - Photochemical oxidants
  - Carbon monoxide, Lead, etc.
- **Urban areas most affected**
  - Sao Paulo, BRAZIL
  - Santiago, CHILE
  - Mexico City, MEXICO

Respire Profundo !!

CO_2 SO_x NO_x …

Ciudad de Mejico

- 1/3 deaths is for Environmental issues
- Worst Pollution
- Local Geography makes the problem worst !



Santiago - CHILE

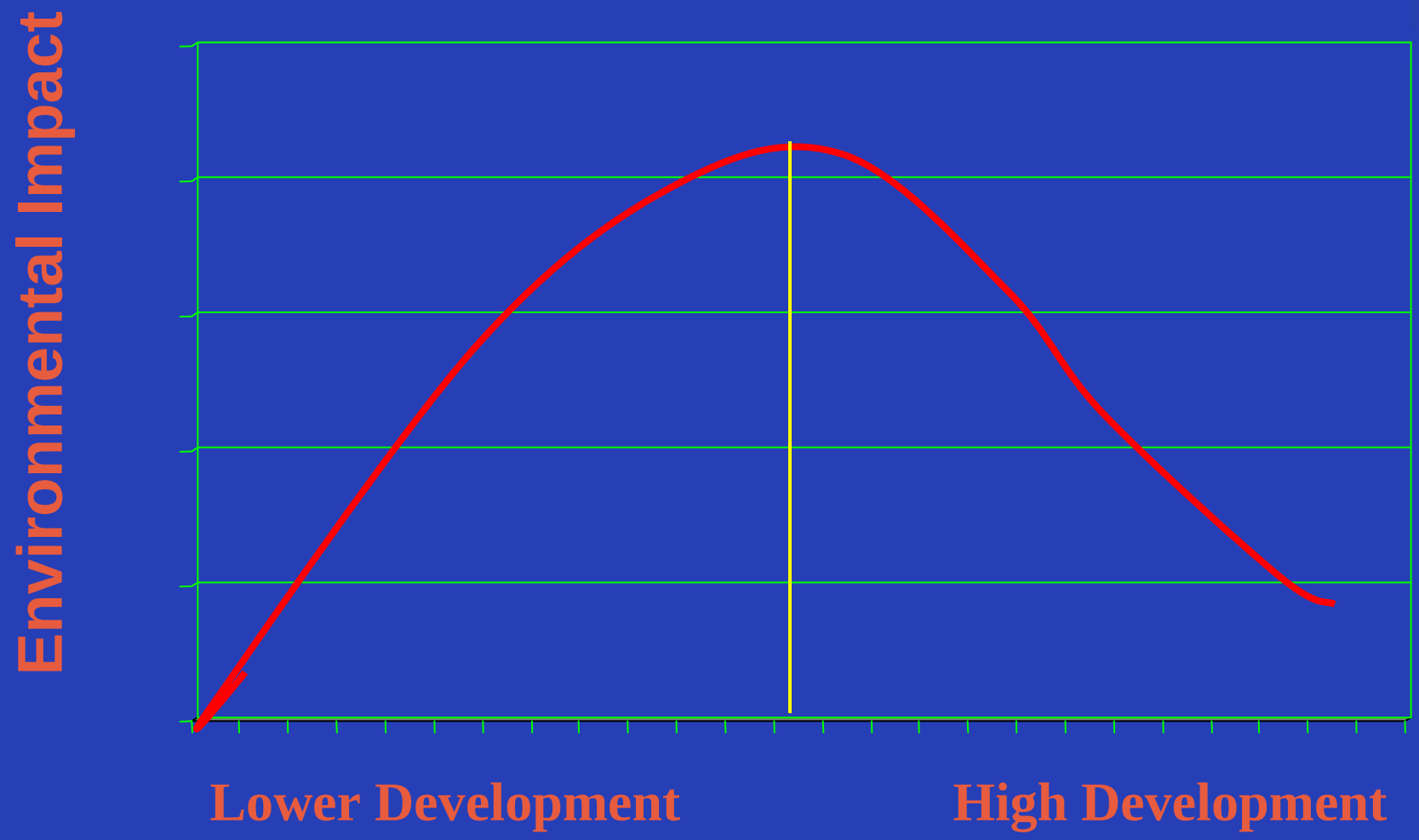
MEDIO AMBIENTE

FPL workers at Orlando International Airport

87 Snakes

Alligator 20 ft

Development – Energy – Environment



Kyoto - NAFTA - Ozone Layer

- Planting Trees …
  to Offset Others Emissions
- Pollution Control: What Standard ?
- Competitiveness
- Health – Life
- **CONTROL:** by WHO ?? - WTO ??

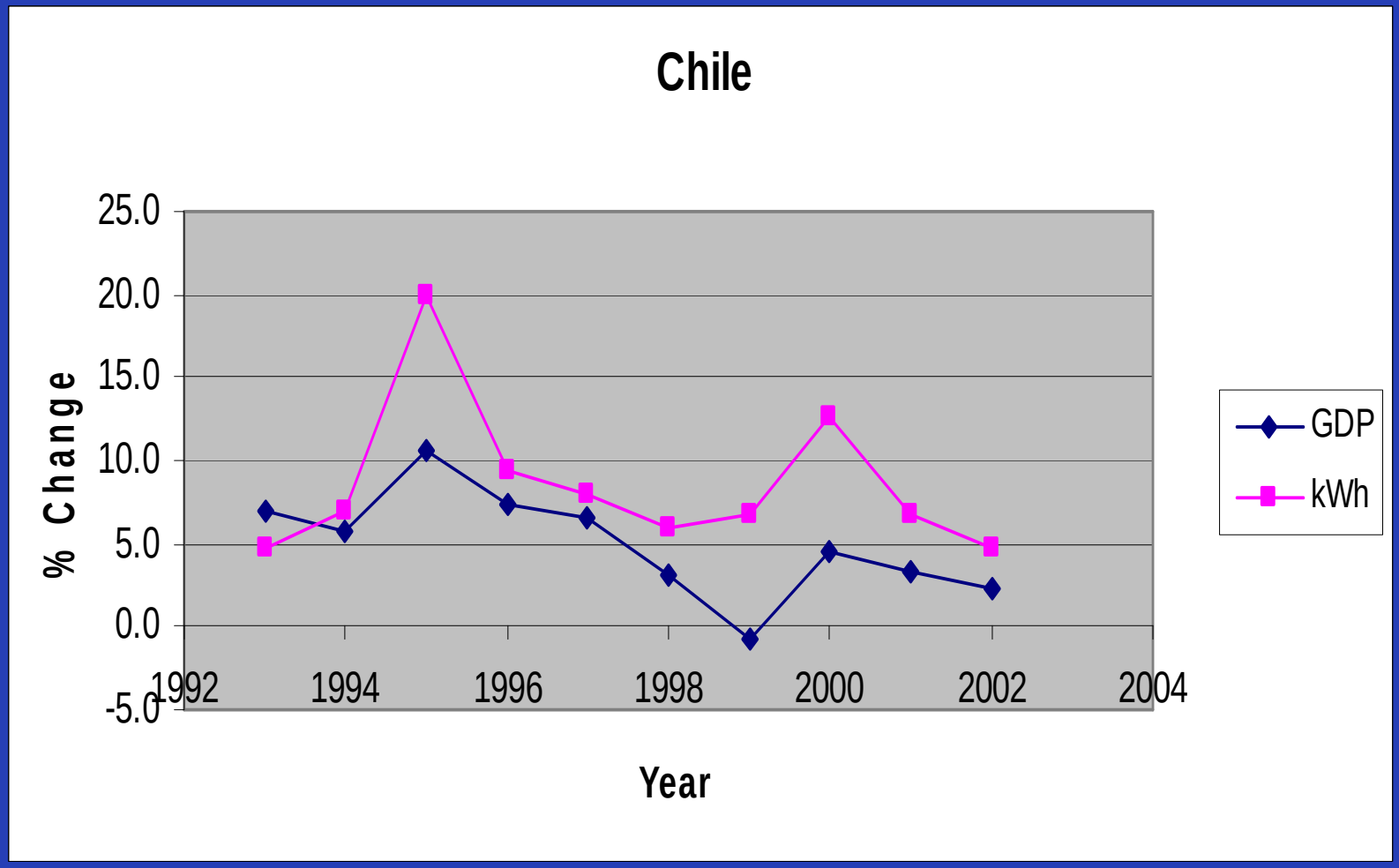
RED the BIOGAS Part of the Solution

Electricity en America del Sur

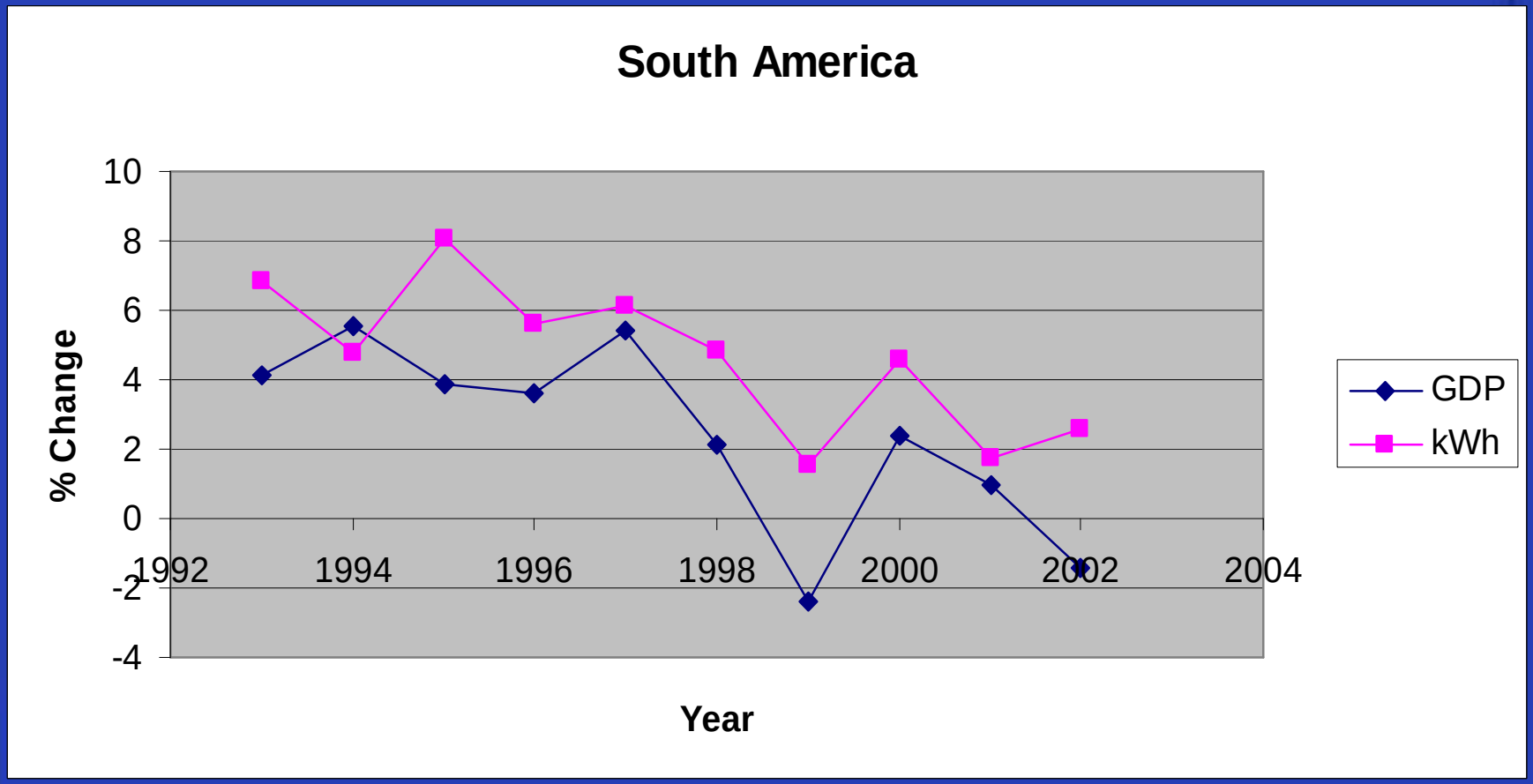
- Alto crecimiento de Consumo de Energia
- Hidroelectricity: Principal Fuente de Electricidad
- Alrededor del 90% de la poblacion tiene acceso

Uruguay: 95% **Bolivia: 61%**

ENERGIA y DESARROLLO



ENERGIA y DESARROLLO



Correlation kWh and GDP for all SA (-3) is 0.79 , a high value

ENERGIA EN CHILE

- País dependiente de Energia
- No posee grandes reservas de E.
- Casi la totalidad del GN consumido en el país es importado
- Hay 4 Sistemas Interconectados:
  - SI del Norte Grande
  - SI Central
  - SI de Aisén y Magallanes

Desarrollo: El Modelo ESEPE

- 5 desafios basicos
  - Educacion
  - Sociedad
  - Economia
  - Politica
  - Ecologia

Educacion

- Medio fundamental para transformar y preparar a individuos y sus comunidades
- El Cancer de la Hiperignorancia:

"Una nacion puede tener muchos posos petroleros, muchas minas de metales preciosos, muchas tierras fertiles, muchas riquezas marinas, muchos bosques tropicales y muchos otros recursos naturales, pero si los cerebros de sus niños estan vacios, esa nacion no tiene futuro"

Regional Challenges

	Education		Scientific Capabilities			Information flows	
	School enrollment tertiary (% age group) 2000	School enrollment secondary(% age group) 2000	Scientists in R&D (per million) 2000	Scientific & tech. journal articles 1999	US patents (per million) 2001	Internet users, percent of population 2001	Phone subscribers per 1000 people (fixed and mobile) 2000
Argentina	*48.0*	96.7	713.4	2361	1.4	8.9%	389
Chile	37.5	75.4	370.1	879	0.8	20.4%	446
Uruguay	36.1	98.1	*218.5*	144	0.0	12.0%	410
Bolivia	35.7	79.6	98.5	33	0.0	1.8%	135
Panama	*34.9*	69.2	*124.5*	37	0.4	3.2%	296
Peru	*28.8*	*80.8*	*228.8*	56	0.2	11.6%	117
Venezuela, RB	28.5	59.3	194.0	448	1.1	5.2%	330
Colombia	23.3	69.8	100.7	207	0.3	2.7%	223
Dominican Republic	*23.1*	59.5		6	0.2	2.2%	187
Mexico	20.7	75.3	*224.7*	2291	0.8	3.7%	267
Ecuador	*17.6*	57.4	*83.3*	20	0.3	2.6%	138
El Salvador	17.5	54.2	46.7	0	0.5	0.8%	204
Brazil	16.5	108.5	323.4	5144	0.6	4.7%	319
Jamaica	16.4	83.3	..	44	0.4	3.9%	341
Costa Rica	16.0	60.2	..	69	0.7	10.1%	274
Honduras	14.7	..		11	0.0	0.6%	70
Nicaragua	*11.8*	54.0	*72.7*	8	0.0	1.0%	49
Paraguay	*10.1*	59.8	..	4	0.0	1.1%	204
Guatemala	*8.4*	37.0	..	14	0.0	1.8%	134
Trinidad and Tobago	6.5	80.8	*144.9*	37	3.1	9.2%	334
Haiti	*1.2*	..		1	0.0	0.4%	16
Reference Countries							
Korea, Rep.	77.6	94.1	2318.6	6675	74.0	51.9%	1060
United States	72.6	95.2	*4099.4*	163526	314.4	50.6%	1054
New Zealand	69.2	112.4	*2197.2*	2375	32.3	28.5%	893
Israel	52.7	93.3	*1563.3*	5025	163.3	28.9%	1184
Greece	*50.5*	98.4	*1400.1*	2241	2.4	13.3%	1097
Ireland	47.5	*109.1*	*2183.7*	1237	37.2	23.6%	1077
Singapore	*43.8*	..	4139.5	1653	72.1	37.3%	1168
Thailand	35.3	81.9	*73.8*	470	0.4	5.8%	143
Malaysia	28.2	70.3	*159.9*	416	1.6	27.9%	412
Hong Kong, China	*27.4*	..	..	1817	34.3	39.0%	1406

Source: World Development Indicators and World Economic Forum.

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Red Energetica Andina Integrada ?

Venezuela	Petroleo
Colombia	Carbon
Ecuador	Petroleo
Peru	Gas Natural
Bolivia	Gas Natural
Chile	Carbon

Transition
1820-1850

Export-led Growth
1850-1914

Transition
1914-1945

Inward-looking Development
1945-1973

Transition
1973-1990

Export-led Growth
1990-2001

ENERGY or WATER
Driven Transition
2001 - ? or EDUCATION ??

Las Preguntas de las PYME

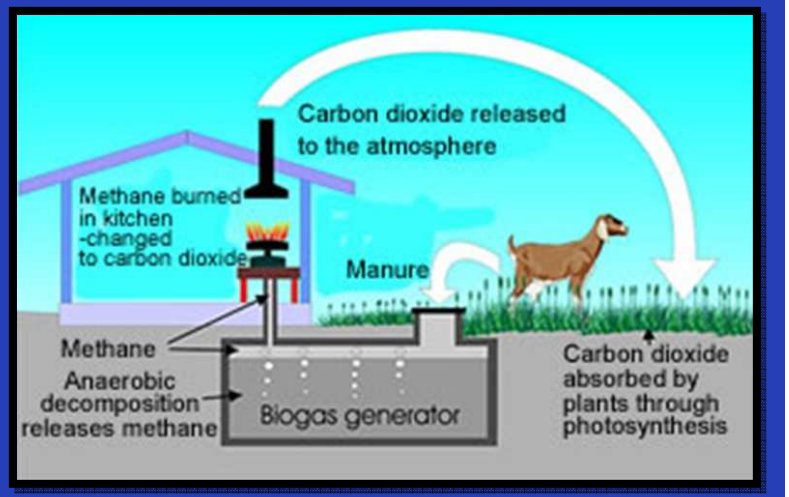
- Que tan Energeticamente Eficiente somos ?
- Donde Estamos ? Benchmarking la Solucion ?
- Que Hacer ?

Uso Eficiente de la Energia

Academia-Universidad-Industria

BIOGAS

Parte de la solucion a la Crisis Energetica - H_2



Non-Traditional Energy Sources Comparison

Energy Source	Implementation Cost	Consumer Cost	Required Resources
Solar	10 to 12 million $/MW	0.15 to 0.25 $/kWh	Solar Radiation
Geothermal	2.5 million $/MW	0.05 $/kWh	Geothermal Reservoir
Tidal	1 million $/MW	1 $/kWh	Tidal Movement
Eolic	1 to 2 million $/MW	0.04 to 0.06 $/kWh	Wind
Fuel Cells	1.5 million $/MW	N/A	Hydrogen
Liquid Propane	N/A	0.104 $/kWh	Oil Well
Gasification	3.8 million $/MW	0.67 $/kWh	Organic Materials
Bituminous Coal	42.40 $/Ton	0.07 $/kWh	Coal
Hydrogen	N/A	30 $/kWh	Water
Biomass	N/A	N/A	Organic Materials
Biofuel	N/A	0.035 $/kWh	Organic Materials
Batteries	N/A	N/A	Mutiple

EFFICIENCY: The Dormant Giant

Faculty, Students and Industry should work together to:

- ***Improve*** Industrial Energy Efficiency
- ***Increase*** productivity
- ***Reduce*** emissions and waste

Some Energy Audits Results:

- ***Proposed Annual Savings:*** $7.0 millions
- ***Real Implemented Savings:*** $1.5 millions

ENERGY AUDIT

- Processes with less Energy = EM Programs

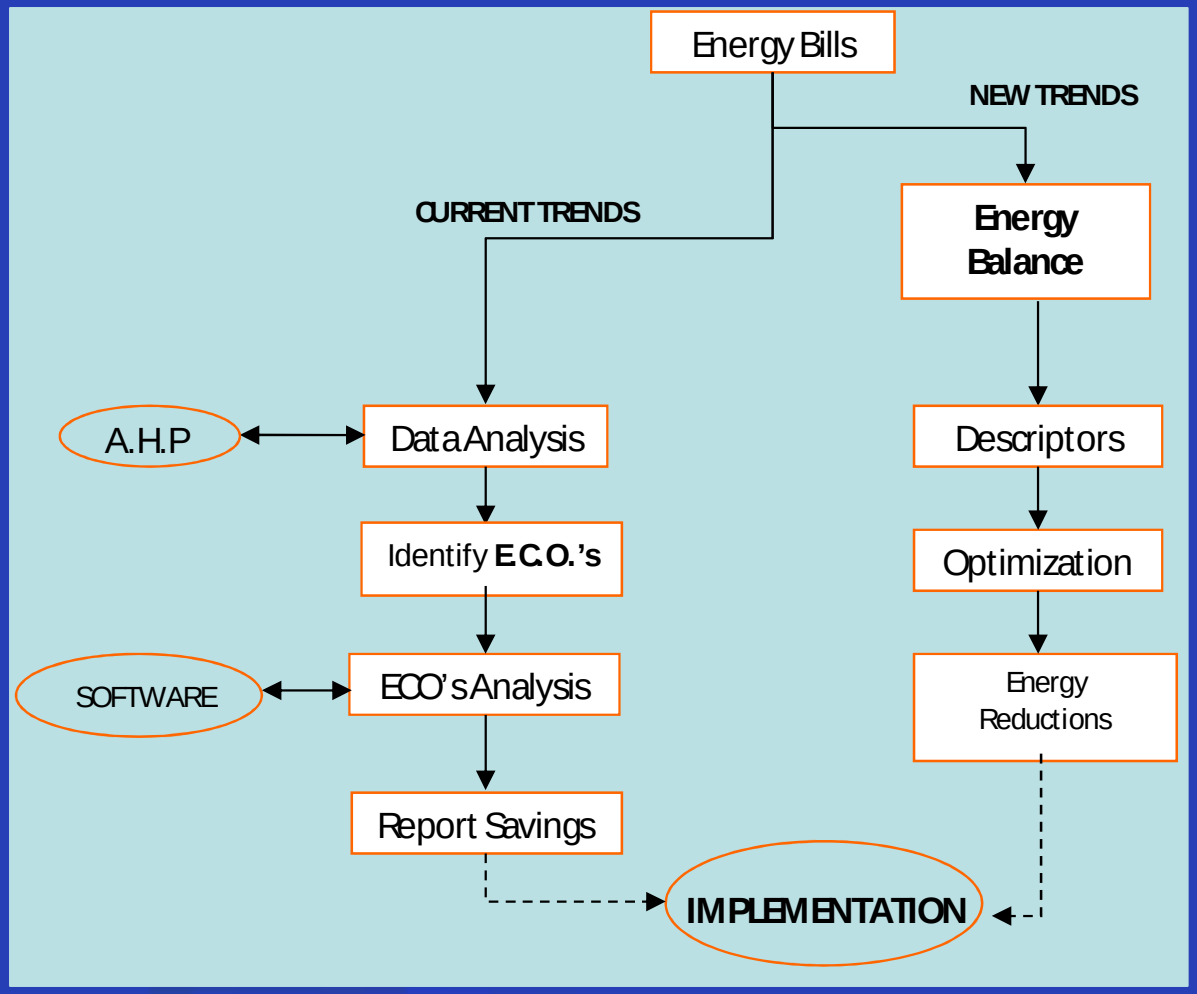
Energy Audit = Optimum Energy Consumption

Bottom Line Impact

Academia + Government + Industry = Maximize Benefits.

Energy Audit = Quantify Energy and Cost Savings.

The EM Program Scheme



Goal: Account for the electric energy consumed by each piece of equipment

Orange Juice Production Process

Receiving

↓

Extracting

↓

Evaporating

↓

Blending

↓

Packaging

↓

Storing

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Company Profile

Table 1. Average Company Profile (SIC 2033)

Sales ($/yr)	Annual Production	Production Area ft^2	Production Area $\$/ft^2$	Emps.	Taxes Prog.	E. Savings ($/yr)	% E Savings
140,000,000	3,400,000 gallons of Conc.	100,341	1395.24	140	Yes	189,709 (9)	23.68

Table 2. Energy Rate Profile Prior to Energy Audits

[redacted]

Proposed Measures

Assessment Recommendations	
Install High Efficiency Lighting	Repair Steam Leaks
Install Combined Heat and Power System	Recover Waste/Exhaust Heat
Install New Refrigeration System	Insulate Facility Roof
Install High Efficiency Motors	Insulate Roof of Tank Farms
Replace V Belts with Cogged V Belts	Turn Off Lights and AC
Turn Off Unused Equipment	Install Occupancy Sensors
Repair Compressed Air Leaks	Remove Unnecessary Lights
Provide Cooler Air for Air Compressor	Schedule Freezers Lights Use
Reduce Compressed Air Pressure	Turn Off Outside Lights
Reduce Lighting in Selected Areas	Install Skylights and Sensors
Retrofit Gas Fired System	Implement a Lights Management System
Adjust Boiler Air/Fuel Ratio	Change Feed Mill Schedule
Increase Frequency of Boiler Tune-up	Install a Light-Bulbs Recycling Unit, etc.

Initial Savings Analysis

- Fraction of Savings

$$F = \sum_{i,j} F_{ij} = \langle S_j \rangle * \left[\frac{C_j}{\sum_{j=1} T_j} \right]$$

Where:

F_{ij} : Counters: i is for kWh = 1 ; kW = 2 ; Cost ($/yr) = 3
j is for the type of piece of equipment.

$\langle Sj \rangle$: Average of Savings (kW, kWh, Cost)

C_j : Current Consumption (kW, kWh, Cost)

T_j : Total Current Distribution according to piece of equipment.

Initial Savings Analysis

Table 3. Energy (E) Conservation Opportunities Savings

	Savings kWh	Savings kW	$/yr	Implementation Cost ($)	SPP years	ROI %/yr
Lighting	111,433	29	6,546	14,274	2.2	46
Motors	1,136,974	52	56,087	30,181	0.5	186
Air Cond.	1,210,020		66,914	75,000	1.1	89
Air Comps.	284,033		15,707	1,050	0.1	1,496
Ammonia Comps.	541,672		29,954	45,000	1.5	67
Hydraulic Comps.						
Refrig. Comps.	17,242		953	2,500	2.6	38
Chillers	2,108,067		116,576	40,000	0.3	291
Heaters	77,582		4,290	31,741	7.4	14
Dehumidifiers	1,557,563	555	98,459	15,000	0.2	656
Miscellaneous	416,040		23,007	16,000	0.7	144
TOTAL Savings	**7,460,625**	**636**	**418,494**	**270,745**	**0.6**	**155**

- We consider the average of energy savings and the fraction that corresponds to energy usage for each type of equipment piece.

Proposed Model and Descriptors

α: Energy savings Rate (% imposed)

C_j: Unit Cost per kWh of group j.

X_j: Decision Variable. Amount of KWh of group j.

- Analysis of X_j implies the reduction of Demand (kW), the amount (number) of equipment, pieces, etc.

Proposed Model and Descriptors

- Objective Function: Total Energy Use

$$Min\ Z = \sum_j \left(\sum_i \frac{C_{ij}}{kWh_{ij}} \right) x_j$$

- In here, since X_j represents the possibilities for energy reduction, translated from kW, kWh, number of pieces if equipment and hours of usage.

$$Z = Totals\left(1 - \frac{\alpha}{100}\right) x_j = K_i \left(1 - \frac{\alpha}{100}\right)$$

With

$$x_j \geq 0$$

and

s.t.

$$\sum_{j=1} \left[\sum_{i=1} \frac{C_{ij}}{kW_{ij}} \right] \left(\frac{x_j}{H_j} \right) \leq \sum_{j=1} \sum_{i=1} C_{ij}$$

Where H_j is the number of hours that group j equipment is ON.

APPENDIX: EQUIPMENT LIST AND ENERGY BALANCE

LIGHTING

Location	Watts	No Fixtures	No lamps	Hours/yr	Ballast factor	kW	kWh	Total Cost ($/yr)	
Maintenance	40	9	2	2,600	1.15	0.8	2,153	$214	
Maintenance	34	1	2	2,600	1.15	0.1	203	$20	
Conference	34	6	4	2,600	1.15	0.9	2,440	$242	
Offices	34	20	4	2,600	1.15	3.1	8,133	$807	**GROUP 1**
Break Room	34	1	4	2,600	1.15	0.2	407	$40	
Hallway	34	20	4	2,600	1.15	3.1	8,133	$807	
Lockers	34	12	4	2,600	1.15	1.9	4,880	$484	
USDA Room	34	4	4	2,600	1.15	0.6	1,627	$161	
Feed Mill	250	22	2	4,896	1.20	13.2	64,627	$5,224	
Feed Mill Collection	75	2	1	4,896	1.20	0.2	881	$71	
Walkway	75	2	1	4,896	1.20	0.2	881	$71	
Miscellaneous	1,000	1	1	4,896	1.20	1.2	5,875	$475	
Orange Segregation	250	40	1	4,896	1.20	12.0	58,752	$4,749	
Other	175	10	1	4,896	1.20	2.1	10,282	$831	
Boiler Room	34	10	2	4,896	1.15	0.8	3,829	$309	
Maintenance	34	6	2	4,896	1.15	0.5	2,297	$186	**GROUP 2**
Feed Mill	40	4	2	4,896	1.15	0.4	1,802	$146	
Maintenance	34	6	2	4,896	1.15	0.5	2,297	$186	
Inspection & Lab	60	8	2	4,896	1.20	1.2	5,640	$456	
Storing Park	34	4	2	4,896	1.15	0.3	1,531	$124	
Motor Area	40	10	2	4,896	1.15	0.9	4,504	$364	
Grade Area	60	3	2	4,896	1.20	0.4	2,115	$171	
Freezer	400	24	1	5,712	1.20	11.5	65,802	$5,123	**GROUP 3**
Freezer	40	5	2	5,712	1.15	0.5	2,628	$205	
Subtotal Lighting						**45.7**	**233,744**	**$18,691**	

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MOTORS

Location	HP	No. of units	No. of hours	LF	Efficiency	kW	kWh	Total Cost ($/yr)
Evaporators CT	5	12	4,896	0.560000002	0.88	28.6	139,933	$11,311
Evaporators CT	10	7	4,896	0.560000002	0.91	32.3	158,204	$12,788
Evaporators CT	8	2	4,896	0.560000002	0.90	7.0	34,241	$2,768
Evaporators CT	15	1	4,896	0.560000002	0.91	6.9	33,752	$2,728
Evaporators CT	50	1	4,896	0.560000002	0.94	22.3	109,260	$8,832
Evaporators CT	30	3	4,896	0.560000002	0.93	40.5	198,150	$16,017
Coolers	15	8	4,896	0.560000002	0.91	55.1	270,014	$21,826
Coolers	10	7	4,896	0.560000002	0.91	32.3	158,204	$12,788
Belts	5	15	4,896	0.560000002	0.88	35.7	174,916	$14,139
Receiving	10	4	4,896	0.560000002	0.91	18.5	90,402	$7,308
Evap Pump	10	5	4,896	0.560000002	0.91	23.1	113,003	$9,134
Boiler Room	30	2	4,896	0.560000002	0.93	27.0	132,100	$10,678
Boiler Room	10	3	4,896	0.560000002	0.91	13.8	67,802	$5,481
Waste Water	10	3	4,896	0.560000002	0.91	13.8	67,802	$5,481
Waste Water	20	2	4,896	0.560000002	0.92	18.2	89,122	$7,204
Waste Water	15	1	4,896	0.560000002	0.91	6.9	33,752	$2,728
Waste Water	5	4	4,896	0.560000002	0.86	9.7	47,456	$3,836
Juice Pump	10	2	4,896	0.560000002	0.91	9.2	45,201	$3,654
Juice Pump	5	1	4,896	0.560000002	0.88	2.4	11,661	$943
Pulp Finisher	8	1	4,896	0.560000002	0.90	3.5	17,121	$1,384
Aux Pump	20	1	4,896	0.560000002	0.92	9.1	44,561	$3,602
Box Machine	5	1	4,896	0.560000002	0.88	2.4	11,661	$943
Fruit Stack-Destack	3	7	4,896	0.560000002	0.86	10.2	49,829	$4,028
Centrifuge	30	2	4,896	0.560000002	0.93	27.0	132,100	$10,678
Centrifuge	40	2	4,896	0.560000002	0.93	36.0	176,134	$14,237
Centrifuge	20	3	4,896	0.560000002	0.92	27.3	133,683	$10,806
Centrifuge	10	1	4,896	0.560000002	0.91	4.6	22,601	$1,827
Pumps	10	10	4,896	0.560000002	0.90	46.6	228,276	$18,452
Pulp Finisher	10	3	4,896	0.560000002	0.91	13.8	67,802	$5,481
Juice Belts (Extr)	10	6	4,896	0.560000002	0.91	27.7	135,604	$10,961
Separation Belts	10	3	4,896	0.560000002	0.91	13.8	67,802	$5,481
Tables	10	6	4,896	0.560000002	0.83	30.3	148,214	$11,981
Roller Tables	2	4	4,896	0.560000002	0.83	4.0	19,762	$1,597
Subtotal Motors						**659.7**	**3230124.0**	**261101.7**

GROUP 4

AIR CONDITIONING

Location	Tons	No. of units	SEER	No. of hours		kW	kWh	Total Cost ($/yr)	
Office	10	1	8	2,600		15.0	39,000	$3,870	GROUP 5
Office	15	1	10	2,600		18.0	46,800	$4,644	
Subtotal Air Conditioning		**COP**	**2.7**			**33.0**	**85,800.0**	**8,514.0**	

AMMONIA COMPRESSORS

Location	HP	Units	No. of hours	LF	Efficiency	kW	kWh	Total Cost ($/yr)	
Rect - Cold Rooms	100	8	4,896	0.560000002	0.944	354.03	1,733,350.0	82,980	GROUP 6
						354.0	**1,733,350.0**	**82,980**	

HYDRAULIC COMPRESSORS

Location	HP	Units	No. of hours	LF	Efficiency	kW	kWh	Total Cost ($/yr)	
Hydraulic Compressors	50	14	4,896	0.560000002	0.94	312.4	1,529,644	$73,228	GROUP 7
						312.4	**1,529,644**	**$73,229**	

AIR COMPRESSORS

Location	HP	Units	No. of hours	LF	Efficiency	kW	kWh	Total Cost ($/yr)	
Fruit Receiving	25	2	4,896	0.56	0.91	23.0	112,382	$9,084	GROUP 8
Water Treatment	100	2	4,896	0.56	0.91	91.8	449,528	$36,337	
Subtotal Air Compressors						**114.8**	**561,910.1**	**45,421.1**	

CHILLERS

Location	HP	Units	No. of hours	LF	Efficiency	kW	kWh	Total Cost ($/yr)	
Area 1	20	2	2,172	0.56	0.91	18.4	39,928	$4,289	GROUP 9
Area 2	30	1	2,172	0.56	0.93	13.5	29,365	$3,154	
Area 3	50	1	2,172	0.56	0.93	22.5	48,941	$5,257	
Subtotal Chillers						**54.4**	**118,234.8**	**12,701.0**	
MISCELLANEOUS (1.0%)						18	75,984	5,110	
TOTAL						1,592	7,568,791	507,747	
MIN ACTUAL kW						1,480			
MAX ACTUAL kW						2,000			
ACTUAL CONSUMPTION						1,800	7,598,369	511,000	
ERROR IN kWh (%) & Cost (%)							***0.39%***	***0.64%***	

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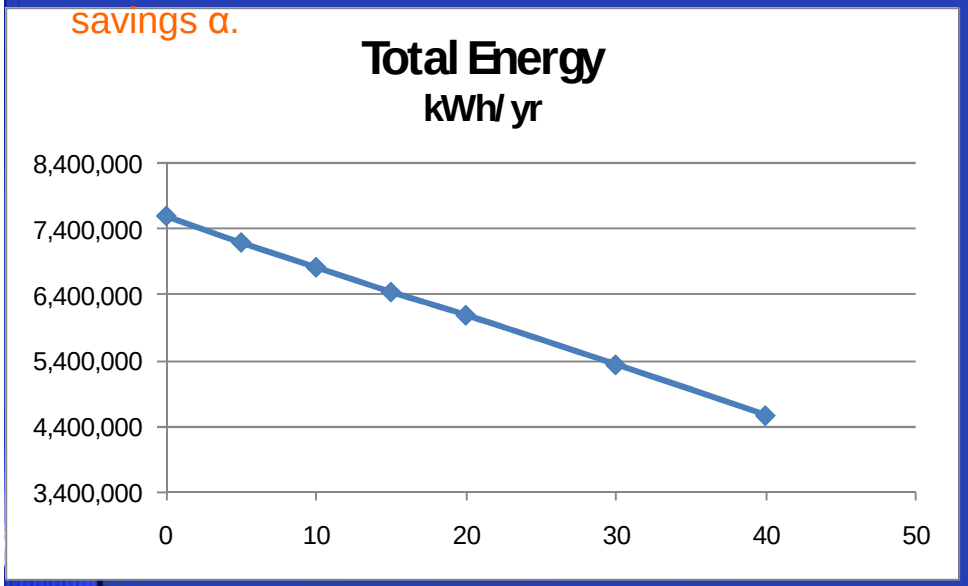
Proposed Model and Descriptors

Lighting & Motors: Energy Only & Cost

Table 7: Factors X, a for different values of α. (Without demand savings) Total Costs and Energy values are also displayed.

	α=0		α=5		α=10		α=15		α=20		α=30		α=40	
N	**X**	**a**	**X**	**a**	**X**	**a**	**X**	**a**	**X**	**a**	**X**	**a**	**X**	**a**
1	3,497	**0.794**	3,497	0.810	3,497	0.829	3,497	0.849	3,497	0.872	3,497	0.928	3,497	1.003
2	11,808	1.132	11,808	1.147	11,808	1.164	11,808	1.183	11,808	1.205	11,808	1.257	11,808	1.326
3	2,542	2.419	2,539	2.452	2,535	2.488	2,531	2.528	2,527	2.574	2,516	2.684	2,504	2.832
4	97,883	2.668	97,883	2.704	97,883	2.744	97,883	2.789	97,883	2.839	97,883	2.962	97,883	3.126
5	42,900	0.198	42,900	0.203	42,900	0.207	42,900	0.212	42,900	0.218	42,900	0.232	42,900	0.251
6	1,733,350	0.048	1,733,350	0.082	1,733,350	0.083	1,733,350	0.085	1,733,350	0.086	1,733,350	0.090	1,733,350	0.095
7	1,529,644	0.048	1,529,644	0.082	1,529,644	0.083	1,529,644	0.085	1,529,644	0.086	1,529,644	0.090	1,529,644	0.095
8	280,955	0.162	280,955	0.164	280,955	0.166	280,955	0.169	280,955	0.172	280,955	0.180	280,955	0.189
9	39,412	0.322	39,412	0.328	39,412	0.338	39,412	0.346	39,412	0.358	39,412	0.383	39,412	0.415
Total Cost	619,158		595,456		572,894		550,332		527,824		482,699		437,520	
kWh	7,596,766		7,194,151		6,819,511		6,444,870		6,092,609		5,340,531		4,571,668	

Energy as function of the rate of savings α.



Total Energy Cost as a function of the rate of savings α.

Proposed Model and Descriptors

- In order to verify the new proposal, we add a second parameter ε, which account for demand savings as we replace lighting for lower wattage units and lower hours of work.
- Also, increase motors efficiency (Keep 0.91 and replace lower for premium 0.94).
- When ε is included, a similar reduction on energy use is obtained, but with bigger slope.

$$E = -74928\alpha + 7,596,766$$

$$E_\varepsilon = -72790\alpha + 7,382,575$$

$$C = -4512\alpha + 619,158$$

$$C_\varepsilon = -4384\alpha + 601.960$$

Proposed Model and Descriptors

Lighting & Motors: Energy, Demand & Cost

Table 8: Factors X, a for different values of α. (With demand savings) Total Costs and Energy values are also displayed.

	α=0		α=5		α=10		α=15		α=20		α=30		α=40	
N	**X**	**a**	**X**	**a**	**X**	**a**	**X**	**a**	**X**	**a**	**X**	**a**	**X**	**a**
1	3,443	**0.794**	3,271	0.810	3,443	0.829	3,443	0.849	3,443	0.872	3,443	0.928	3,443	1.003
2	7,515	1.132	7,139	1.147	7,515	1.164	7,515	1.183	7,515	1.205	7,515	1.257	7,515	1.326
3	995	2.419	993	2.452	992	2.488	990	2.528	989	2.574	985	2.684	980	2.832
4	94,489	2.668	94,489	2.704	94,489	2.744	94,489	2.789	94,489	2.839	94,489	2.962	94,489	3.126
5	42,900	0.198	42,900	0.203	42,900	0.207	42,900	0.212	42,900	0.218	42,900	0.232	42,900	0.251
6	1,733,350	0.081	1,733,350	0.082	1,733,350	0.083	1,733,350	0.085	1,733,350	0.086	1,733,350	0.090	1,733,350	0.095
7	1,529,644	0.081	1,529,644	0.082	1,529,644	0.083	1,529,644	0.085	1,529,644	0.086	1,529,644	0.090	1,529,644	0.095
8	280,955	0.162	280,955	0.164	280,955	0.166	280,955	0.169	280,955	0.172	280,955	0.180	280,955	0.189
9	39,412	0.322	39,412	0.328	39,412	0.337	39,412	0.346	39,412	0.358	39,412	0.383	39,412	0.415
Total Cost	601,960		578,901		556,981		535,062		513,196		469,357		425,463	
kW	1,528		1,528		1,528		1,528		1,528		1,528		1,528	

Figure 9: Energy as function of the rate of savings α.

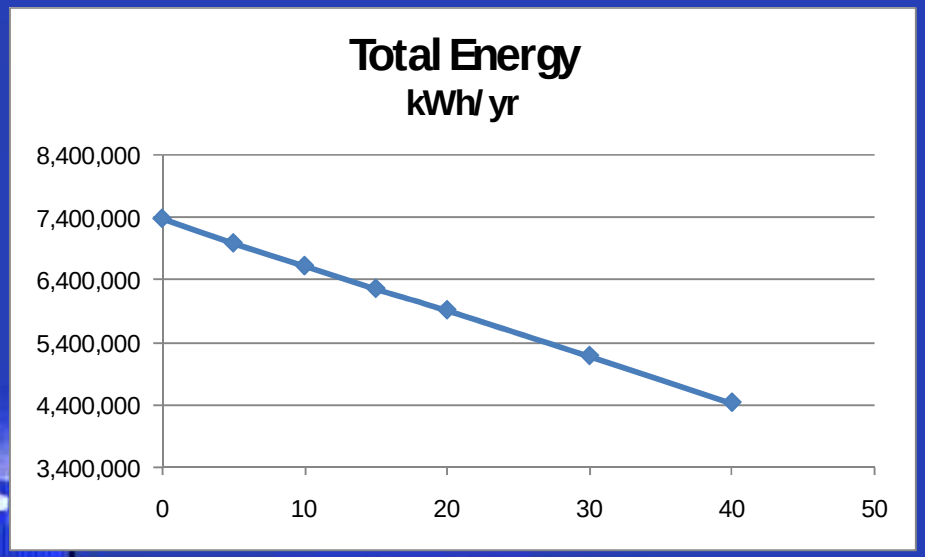
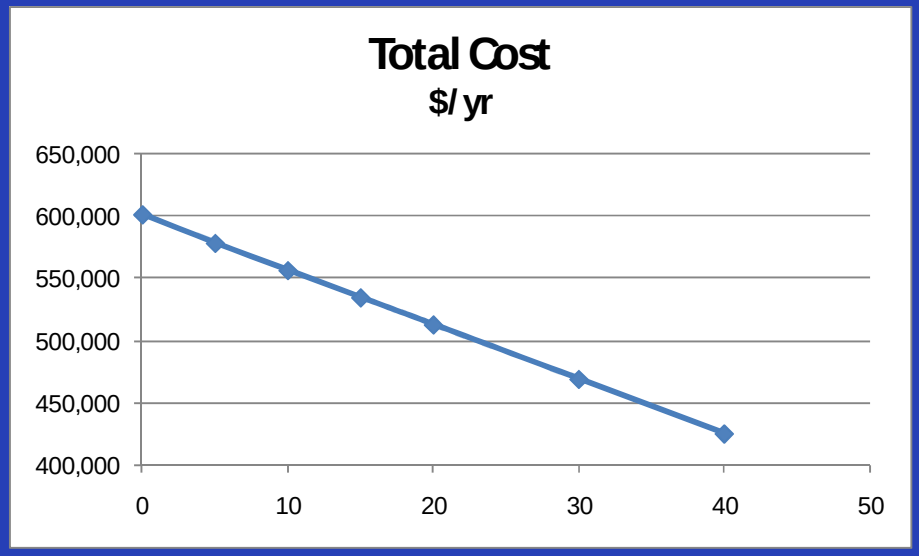
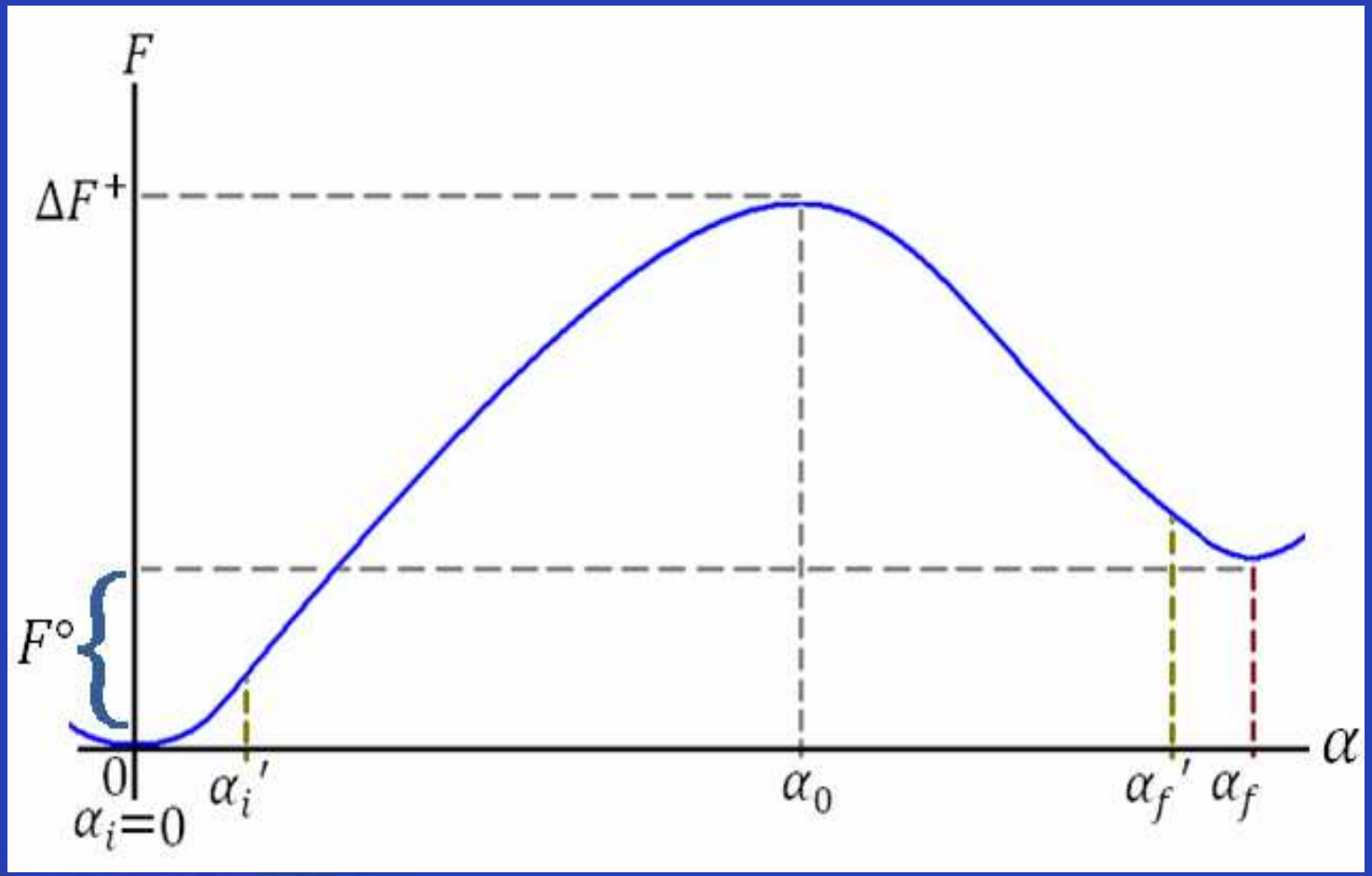


Figure 10: Total Energy Cost as a function of the rate of savings α.



Wind Power Algorithm

- We consider a system of periodicity: $p = \pi/b$
- For convenience we use π/b , where: $b = p/2$



The Algorithm

$$F(b\alpha) = F_o + \sum_{k=1}^{3} F_i \cos(kb\alpha_i)$$

$$f(b\alpha) = \partial F(b\alpha)/\partial\alpha = - b \Sigma k I_k \sin(kb\alpha)$$

$$K(b\alpha) = \partial^2 F(b\alpha)/\partial\alpha^2 = - b^2 \Sigma k^2 I_k \cos(kb\alpha)$$

The Curvature

$$F(b\alpha) = F(b\alpha_l) + f_l(b\alpha - b\alpha_l) + K_l(b\alpha - b\alpha_l)^2 / 2$$

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The Harmonic Approximation

$$K_l = 2\,[\,F(b\alpha) - F(b\alpha_l)\,] / (\alpha - \alpha_l)^2 / 2 \qquad l = i, f$$

The Step

$$\alpha'_i = (N\times 10^\circ / b) - \alpha_i \qquad \alpha'_f = \alpha_f - (N\times 10^\circ / b)$$

The Input

$$\Delta FI^\circ = F(b\alpha_f) - F(b\alpha_i) = -\Sigma F_k\,[\,1 - \cos(kb\alpha_f)$$

$$\cos(b\alpha_o) = \{F_2 \pm \sqrt{(F_2)^2 + 3F_3(4F_1 + 3\,\Delta F^o)}/2\} / 6F_3$$

The Coefficients

$$F_1 = [\, \boldsymbol{K_i} - \boldsymbol{K_f} - 9\, b^2\, \Delta I^\circ] / 16b^2$$

$$F_2 = -[\, \boldsymbol{K_i} + \boldsymbol{K_f}\,] / 8b^2$$

$$F_3 = -[\, \boldsymbol{K_i} - \boldsymbol{K_f} - b^2\, \Delta I^\circ] / 16b^2$$

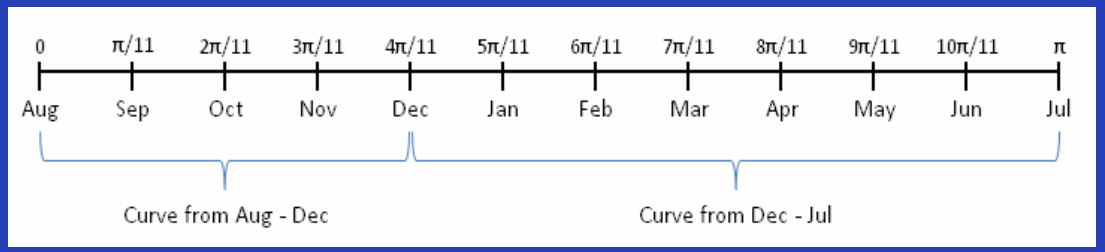
$$F_o = -\Sigma F_k = [\, \boldsymbol{K_i} + \boldsymbol{K_f} + 4\, b^2\, \Delta F^\circ] / 8b^2$$

The Maximum Wind Power (α_o)

$$\alpha_o = b^{-1} \arccos \{[F_2 \pm (0.5 \times [F_2 + 3F_3 (4F_1 + 3\Delta F^\circ)]\,)^{1/2}\,] / 6F_3\,\}$$

Data (Parsing)

- Two distinct curves



- Curves are normalized to (0,0) for the (x,y) coordinates
- Each curve has a different *p*-value and a different *b*-value

August to December:

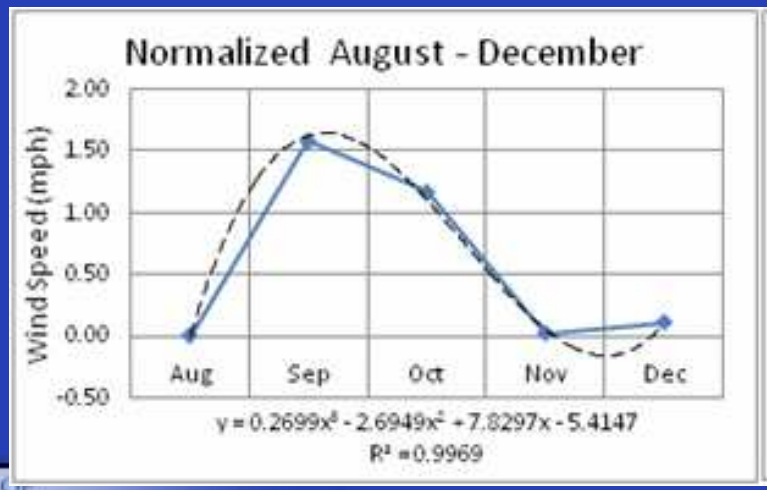
Periodicity *p=4π /11* rad

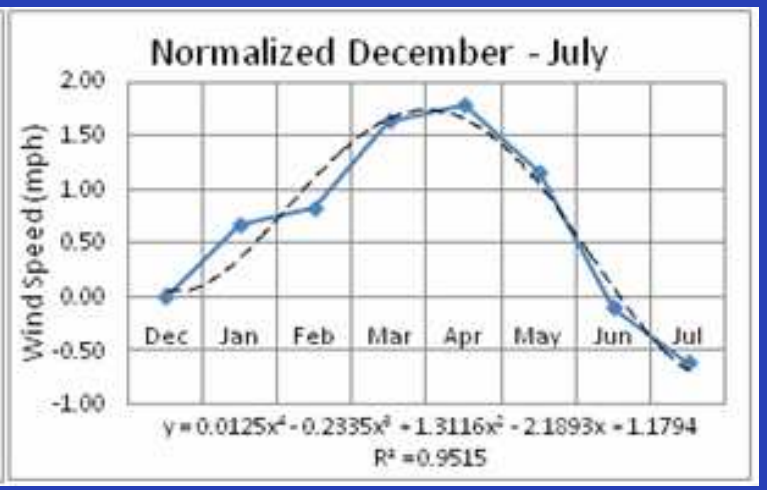
Symmetry parameter *b=11/4* or (65.45°)

December to July:

Periodicity *p=7π /11* rad

Symmetry parameter *b=11/7* or (114.54°)





Results (August – December)

Initial Point (i)

	Alpha i	x(0,0)	F(Alpha i)
Deg	0	0.00	-0.0100

	Alpha i '	x(0,0)	F(Alpha i ')
Deg	10.00	0.22	0.6203
Rad	0.1745		

Final Point (f)

	Alpha f	x(0,0)	F(Alpha f)
Deg	57.1	3.51	-0.1583

	Alpha f '	x(0,0)	F(Alpha f ')
Deg	53.5	3.29	-0.1138

Input Data

Ki = 41.3865 **Kf** = 2.9233

Delta F

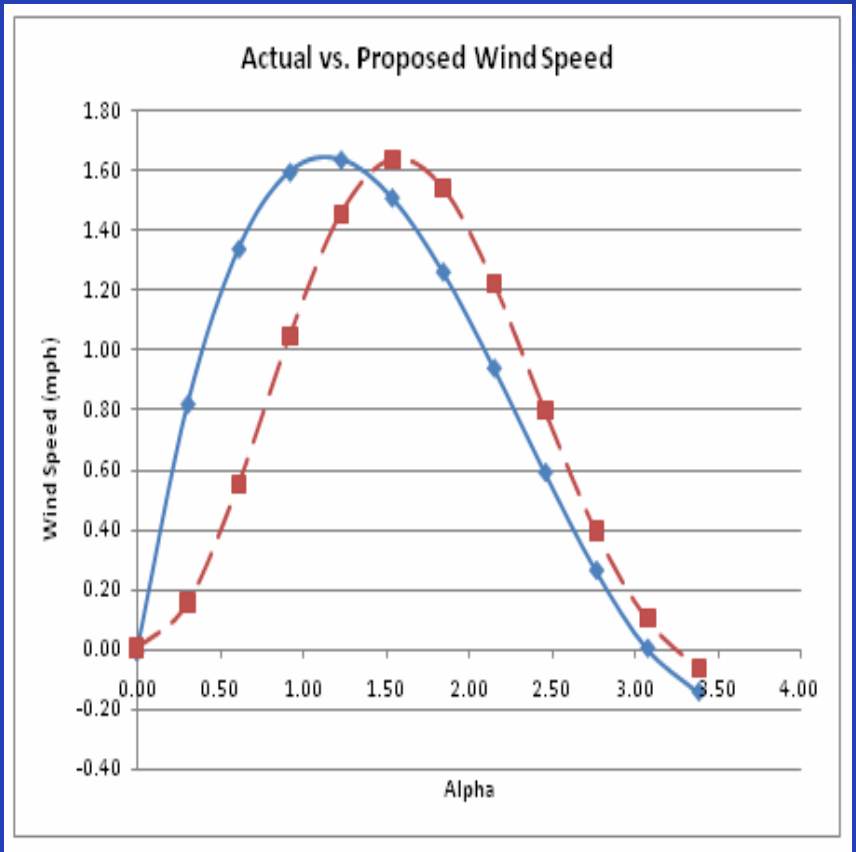
Delta F= -0.1483

Calulate F's

F1= 0.4013 **F2=** -0.7324

F3= -0.3271 **F0=** 0.6582

Output Data



Step-size of α = 5° = 0.18rad

Results (December - July)

Initial Point (i)

	Alpha i	x(0,0)	F(Alpha i)
Deg	0	0.00	0.0807

	Alpha i '	x(0,0)	F(Alpha i ')
Deg	9.00	0.39	0.0899
Rad	0.1571		

Final Point (f)

	Alpha f	x(0,0)	F(Alpha f)
Deg	115	7.00	-0.7446

	Alpha f '	x(0,0)	F(Alpha f ')
Deg	108.6	6.61	-0.5074

•Input Data

Ki = 0.7444 **Kf =** 19.2286

Delta F

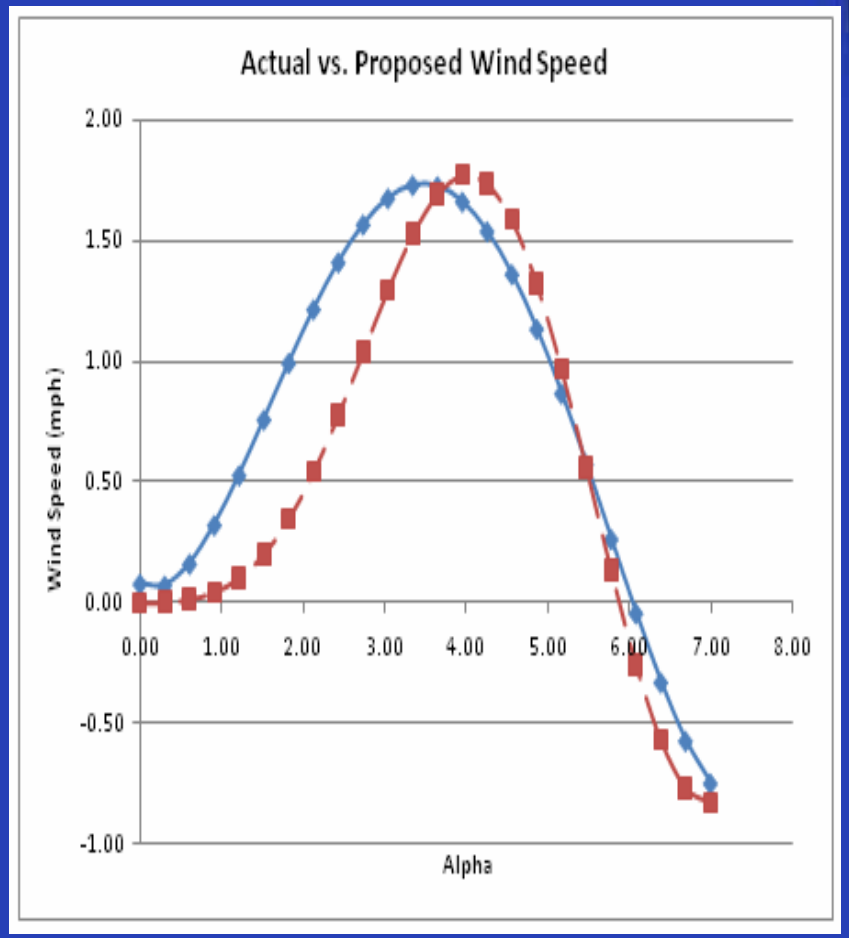
Delta F= -0.8253

Calulate F's

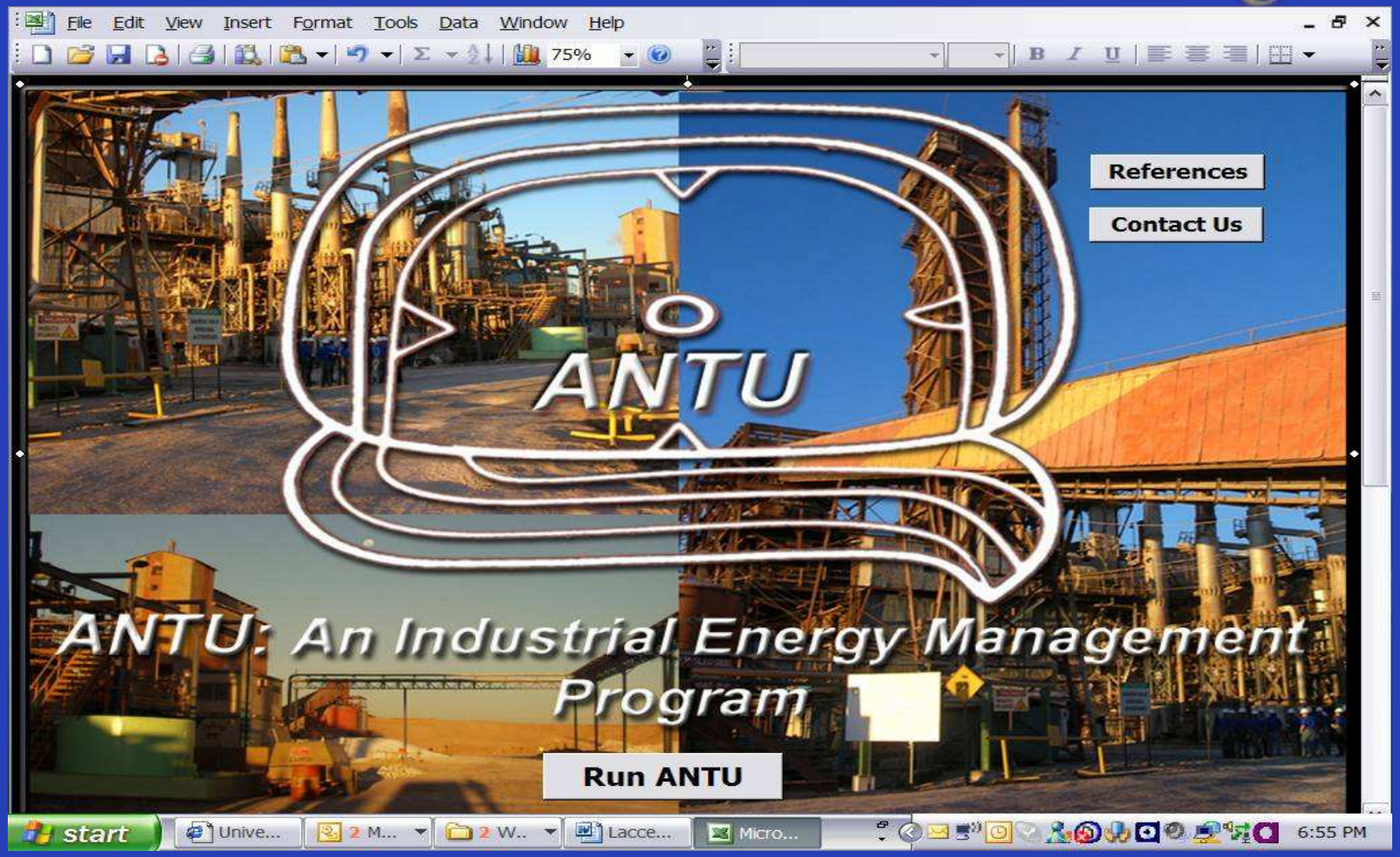
F1= -0.0036 **F2=** -1.0110

F3= 0.4163 **F0=** 0.5984

•Output Data



Step-size of α = 5° = 0.18rad



ANTU: An Industrial Energy Management Package

For Details write to Dr. C. Cradenas: cardenas@ise.ufl.edu

Preguntas ?

GATOR Engineering
UNIVERSITY OF FLORIDA

Eficiencia Energética: El Gigante Dormido

Cristian Cárdenas-Lailhacar

Dept. of Indusntrial and Systems Engineering
University of Florida
303 Weil Hall, P.O. Box 116595
Gainesville, FL 32611

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