Applying Systems Thinking to Energy and Sustainability Challenges in Chile

Jorge Moreno
Donny Holaschutz
Agenda

1. Systems Thinking perspective of the current state of the energy system in Chile and its sustainability

2. How we have used Systems Thinking to attempt to make small contributions and improve the system

3. Areas where we believe Systems Thinking can be used to make a big impact and improve the system
Chilean Electricity Systems - Overview

92% of Population

Northern Interconnected System (SING)
- Installed Capacity: 3.8 GW
- Peak Demand (2012): 2.2 GW
- 100% Thermal:
  - 49% Coal
  - 42% natural gas
  - 9% Oil
- Demand: 85% Mining Industry

Central Interconnected System (SIC)
- Installed Capacity: 13.5 GW
- Peak Demand (2012): 7.2 GW
- 51% Thermal
- 42% Hydro
- 7% Wind/biomass/others

74% of the national demand
92% of population
76% of PIB

Source: Ministerio de Energía, Chile

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Electricity Prices in Chilean Market (spot market)

Northern Interconnected System (SING)

Central Interconnected System (SIC) 92% of Population

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Source: Ministerio de Energía, Chile
Development and Social Tension
System Dynamics

State of the System

Corrective Action

Discrepancy

Goal

State of the System

Corrective Action

Discrepancy

Goal

State of the System

Goal

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Electricity Market Behavior - SIC

*Adapted from Olsina et al. Copyright © 2014 inodú
Electricity Market Behavior - SIC

Source: CNE

Expected Costs (mainly construction, excluding fuel prices)

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Electricity Market Behavior - SIC

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Electricity Market Behavior - SIC

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Electricity Market Behavior - SIC

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Harmony?
Paranal - ESO

Chilean Electric System

Paranal + E-ELT

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Aysén
- Installed Capacity 50 MW

Magallanes
- Installed Capacity 100 MW

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European Southern Observatory (ESO)

ESO’S OBSERVATION FACILITIES IN CHILE

Source: European Southern Observatory

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Paranal + E-ELT
Paranal + E-ELT
Wind Resource

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Wind Resource

Month

kWh/m² per day

Average
Median
Max.
Min.
97%
90%
80%
20%
10%

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Electricity Demand: Paranal

Current Demand (MW) — Paranal

<table>
<thead>
<tr>
<th>Hora</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<td>0.4</td>
<td>0.6</td>
<td>0.8</td>
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<td>3.8</td>
<td>4.0</td>
<td>4.2</td>
<td>4.4</td>
<td></td>
</tr>
</tbody>
</table>

- Summer
- Autumn
- Winter
- Spring

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Electricity Demand: Paranal + E-ELT

Expected Demand (MW) — Paranal + E-ELT

Hora

0  1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17 18 19 20 21 22 23

0  1  2  3  4  5  6  7

Summer Eff  Autumn Eff  Winter Eff  Spring Eff
Summer      Autumn      Winter      Spring

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Current Operation at Paranal

Efficiency Profile – Current Turbine

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Systems Based Approach

1. How does the Energy System Create Value?
2. System Goals
3. Design Space Exploration
4. Definition of Requirements
5. Evaluation of Concepts
6. Definition of Systems Architecture
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Primary System Goal

“The 1000 km² we are sitting on could be the best place for making astronomic observations in the world. The European Southern Observatory’s core business is science and making observations, by focusing on our core we make real impact.” A member of the ESO Team.

SPS: To facilitate astronomical observation at Paranal and Cerro Armazones by powering the observatories facilities in a

1. reliable,
2. cost effective,
3. and environmentally friendly manner.
Value Delivery

Fuel Suppliers

Equipment and Maintenance Services Suppliers

Isolated Power System

Paranal and E-ELT Observatories

Governmental Organizations (MinRel, SEIA, etc)

ESO

Fuel

Technology, Spare Parts, Services

Environmental Compliance

Energy

Permits & Environmental Compliance

Regulatory Compliance based on Historical Context: Decree 18 / 1964 and Decree 1766 / 1977

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Explore the ilities

Maintainability
Modularity
Reliability
Sustainability
Safety
Changeability
Robustness
Agility
Resilience
Versatility
Quality
Flexibility
Durability
Usability
Evolvability
Survivability
Repairability
Interoperability
Reconfigurability
Modifiability
Scalability
Adaptability
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Systems Based Approach

1. System Goals
2. Design Space Exploration (Many Concepts)
3. Definition of Systems Architecture
4. Definition of Requirements
5. Evaluation of Concepts
6. How does the Energy System Create Value?

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Engaged Suppliers to Explore Feasible Alternatives

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Hybrid Systems Design Space

Cases with current Turbine Operating as Backup

Cases with current Turbine Operating as Primary Unit

Cost of Electricity ($USD/kWh)

Tons of Carbon Dioxide Produced Per Year

Actual Consumption at Observatory (3484 Cases)

Variation Introduced to Actual Demand and Renewable Resource (3854 Cases)

Cases with Solar and Fossil Fuel Generator w/o Wind Turbine

Cases with Wind and Fossil Fuel Generator w/o Solar

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Hybrid Systems Design Space

Cost of Electricity
US$/kWh

Cases with current Turbine Operating as Primary Unit

Cases with current Turbine Operating as Backup

Investment Costs ($ Millions USD)
Systems Based Approach

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2. Design Space Exploration (Many Concepts)
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6. How does the Energy System Create Value?

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Specify the “ilities”

<table>
<thead>
<tr>
<th>System Parameters and Qualities</th>
<th>Desired System Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Availability of Recognized Supplier</td>
<td>1. Proven Technology</td>
</tr>
<tr>
<td>2. Existence of Similar Equipment Installed in Chile</td>
<td>2. Maintainability</td>
</tr>
<tr>
<td>3. Maintenance Frequency</td>
<td>3. Robustness</td>
</tr>
<tr>
<td>4. Types of Gas that Could Be Used by Motor</td>
<td>4. Adaptability</td>
</tr>
<tr>
<td>5. Installed Capacity Reserves Available if Biggest Unit Were Taken out of Commission</td>
<td>5. Simplicity</td>
</tr>
<tr>
<td>6. Physical Complexity of Architecture: Number of Generators Installed</td>
<td>6. Independence</td>
</tr>
<tr>
<td>7. Operational Complexity of Architecture: Number of Generators Needed to Supply Hourly Demand</td>
<td>7. Redundancy</td>
</tr>
<tr>
<td>8. Average Efficiency of Systems Operations with Expected Demand</td>
<td>8. Flexibility</td>
</tr>
<tr>
<td>9. Resiliency of Efficiency Against Changes in Demand</td>
<td>9. Evolve-ability</td>
</tr>
<tr>
<td>11. Investment Required</td>
<td>11. Investment Cost Efficiency</td>
</tr>
<tr>
<td>13. Average Cost of Electricity</td>
<td>13. Sustainability</td>
</tr>
<tr>
<td>15. Does It Benefit the Current Situation?</td>
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</tr>
</tbody>
</table>
Defining and Prioritizing Requirements

CRÍTICOS
1. El sistema debe ser capaz de abastecer una demanda que no excederá los 7 MW.
2. El sistema debe ser capaz de suministrar líneas de potencia de características dinámicas planificadas por ESO.
3. El sistema debe tener una disponibilidad anual que superará el 90%.
4. El sistema no debe interferir ambientalmente con los requerimientos necesarios para el desarrollo de observaciones astronómicas.
5. La factibilidad de producir la energía eléctrica requerida por el observatorio no debe afectarse por un cambio en el suministro de tipo de combustible.
6. Ante una falla intempestiva, el sistema debe ser reparable de manera eficaz.
7. El sistema debe tener la capacidad de respaldo para suministrar cargas críticas de, al menos, 625 kW.
8. El sistema debe tener la capacidad tanto de ser operado de manera segura como de fallar de manera segura.

IMPORTANTES
1. El sistema debe ser eficiente desde la perspectiva de consumo de combustible.
2. Ante un cambio en el nivel de demanda planificada, el sistema debería ser capaz de mantener su performance desde la perspectiva de consumo de combustible.
3. El sistema debe ser sometido a mantenimiento de manera efectiva.
4. El sistema debe ser capaz de evolucionar para abastecer nuevos requerimientos de demanda de alrededor de 1 MW.
5. El sistema debe ser simple de operar, particularmente, durante la noche, periodo en el cual el personal de operaciones está en descanso.

DESEABLES
1. El sistema podría incorporar fuentes de generación renovable, no fósiles en particular.
2. La producción de energía podría ser remunerativa, a medio plazo visto desde el punto de vista de emisiones de CO2.
Systems Based Approach

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Look at how the System Satisfies Requirements

Case 1: “Optimal” Dispatch

Case 1: “Forced” Dispatch

Case 2: “Optimal” Dispatch

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## Evaluation of Concepts

### Desired System Properties

|----------------------|--------------------|---------------|----------------|--------------|----------------|--------------|--------------|--------------|-----------------|-------------------------|---------------------------|----------------------|

### System Parameters and Qualities

#### 1. Availability of Recognized Supplier

<table>
<thead>
<tr>
<th>Case 1: 2MW Solar PV - Gas Motor 1x1511</th>
<th>Case 2: 2MW Solar - 4 x Turbines 2614 kW</th>
<th>Case 3: 2MW Solar - 3 X Turbines 2614 kW - Gas Motors 2x1511 kW</th>
<th>Case 4: 2MW Solar - 1 X Turbine 2614 kW - Gas Motors 5x1511 kW</th>
<th>Case 5: 2 MW Solar - 1 X Turbine 2614 kW - Gas Motors 8x900kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Yes; 0: No</td>
<td>I 1 1 0 0 1 NA</td>
<td>C 1 1 2 2 3 NA</td>
<td>C 1 1 2 2 3 NA</td>
<td></td>
</tr>
</tbody>
</table>

#### 2. Existence of Similar Equipment Installed in Chile

<table>
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<th>Case 1: 2MW Solar PV - Gas Motor 1x1511</th>
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<td>C 1 1 2 2 3 NA</td>
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</tr>
</tbody>
</table>

#### 3. Maintenance Frequency

<table>
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<td>I 1 1 0 0 1 NA</td>
<td>C 1 1 2 2 3 NA</td>
<td>C 1 1 2 2 3 NA</td>
<td></td>
</tr>
</tbody>
</table>

### Evaluation of Cases for Paranal +E-ELT

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
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<tbody>
<tr>
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<td>5 5 5 5 5</td>
<td>5 5 5 5 5</td>
<td>5 5 5 5 5</td>
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<td>1: Yes; 0: No</td>
<td>I 1 1 0 0 1 NA</td>
<td>I 1 1 2 2 3 NA</td>
<td>I 1 1 2 2 3 NA</td>
<td>I 1 1 2 2 3 NA</td>
</tr>
<tr>
<td>Scale 2 - 3</td>
<td>C 3 3 3 3 2</td>
<td>C 3 3 3 3 2</td>
<td>C 3 3 3 3 2</td>
<td>C 3 3 3 3 2</td>
</tr>
<tr>
<td>Max 8.4 MW</td>
<td>8.4 7.8 8.2 7.5 7.2 NA</td>
<td>8.4 7.8 8.2 7.5 7.2 NA</td>
<td>8.4 7.8 8.2 7.5 7.2 NA</td>
<td>8.4 7.8 8.2 7.5 7.2 NA</td>
</tr>
<tr>
<td>Max 10 Subsystems</td>
<td>5 5 6 7 10 NA</td>
<td>5 5 6 7 10 NA</td>
<td>5 5 6 7 10 NA</td>
<td>5 5 6 7 10 NA</td>
</tr>
<tr>
<td>Max. 8 Units</td>
<td>3 3 4 5 8 NA</td>
<td>3 3 4 5 8 NA</td>
<td>3 3 4 5 8 NA</td>
<td>3 3 4 5 8 NA</td>
</tr>
<tr>
<td>Max. 35%</td>
<td>27% 23% 28% 29% 35% NA</td>
<td>27% 23% 28% 29% 35% NA</td>
<td>27% 23% 28% 29% 35% NA</td>
<td>27% 23% 28% 29% 35% NA</td>
</tr>
<tr>
<td>1: Moderate; 2: High</td>
<td>I 1 1 2 1 2 NA</td>
<td>I 1 1 2 1 2 NA</td>
<td>I 1 1 2 1 2 NA</td>
<td>I 1 1 2 1 2 NA</td>
</tr>
<tr>
<td>Max. 2614 MW</td>
<td>2.6 2.6 1.5 1.5 0.9 NA</td>
<td>2.6 2.6 1.5 1.5 0.9 NA</td>
<td>2.6 2.6 1.5 1.5 0.9 NA</td>
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<tr>
<td>Max. US$ 19 Million</td>
<td>18 16 17 16 19 420</td>
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<td>18 16 17 16 19 420</td>
<td>18 16 17 16 19 420</td>
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<tr>
<td>Max. US$ 9.3 Million</td>
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</tr>
</tbody>
</table>

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Recommendations

Current State

Solve Current Challenges and Experiment

Connect to SIC

Evolution

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Harmony?

Source: Ministerio de Energía, Chile

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Work on the Delays

Hydrological Conditions

Installed Capacity

Dispatchable Capacity

Reserve

Required Reserve Margin

Spot Prices

Electricity Demand

Electricity Demand Balancing Loop

Socio-Technical Factors

Delay 3

Delay 1

Delay 2

Investment Decision

Expected Profitability (for developers and operators)

Expected Costs (mainly construction, excluding fuel prices)

Expected Price of Fuels

Developers Profit Reinforcing Loop

Long-Term Electricity Prices

Expectations on

Market Dynamic Balancing Loop

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Energy Efficiency Industrial Clients

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Electricity Demand in Chile

Source: 2012 IEA Oil & Gas Security

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Industrial Energy Efficiency Challenges

- Lack of Information
- Lack of Technology
- Lack of Access to Capital
- Competing Investment Opportunities
- Lack of Measurements
- Prioritization of other tasks and initiatives
- Lack of Knowhow
- Focus on Production
- Lack of Culture of Energy Efficiency

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Challenge

Industrial Energy Efficiency Assessment in a Salmon Meal Factory.

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Challenges with Projects

[Diagram showing various factors and loops related to electricity demand, reserve, and market dynamics.]

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Delays Making Investment Decisions

Small-Distributed Projects:
- No Scale
- People with space and resource lack desire or capability to develop
- Higher Costs

Large Projects:
- Perception of Permitting Risks

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Delays Installing Capacity

Small-Distributed Projects:
- Challenges Connecting to the Grid
- Finding Power Off-takers

Large Projects:
- Permitting Challenges - Designed in a purely tecno-economic fashion and social resistance
- Local stakeholders will resist
- Evacuating Power
- Selling Power

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Co-Developing Small Projects (ex. Small-Hydro)

Actively Working on Development and Improving Processes

(1) Applying Best Systems

(2) Thinking Practices at a Small Scale
Challenges with Energy Projects
Energy and Sustainability Projects

- **Value Space** - Accompanying our clients to design energy systems which deliver that value to stakeholders and context.

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Energy and Sustainability Projects

- **Design Space** - Using Systems Thinking to Help Make Decisions Early in the Project - **Even Walk Away!**
Energy and Sustainability Projects

- **Organizational Space** - Designing systems based processes to improve the flow of critical information across, into and out of energy infrastructure projects.
Strategy through Elegant Energy Projects

Jointly Discover the Sweet Spot

Design Space

Value Space

Organization Space

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Applying Systems Thinking to Energy and Sustainability Challenges in Chile

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