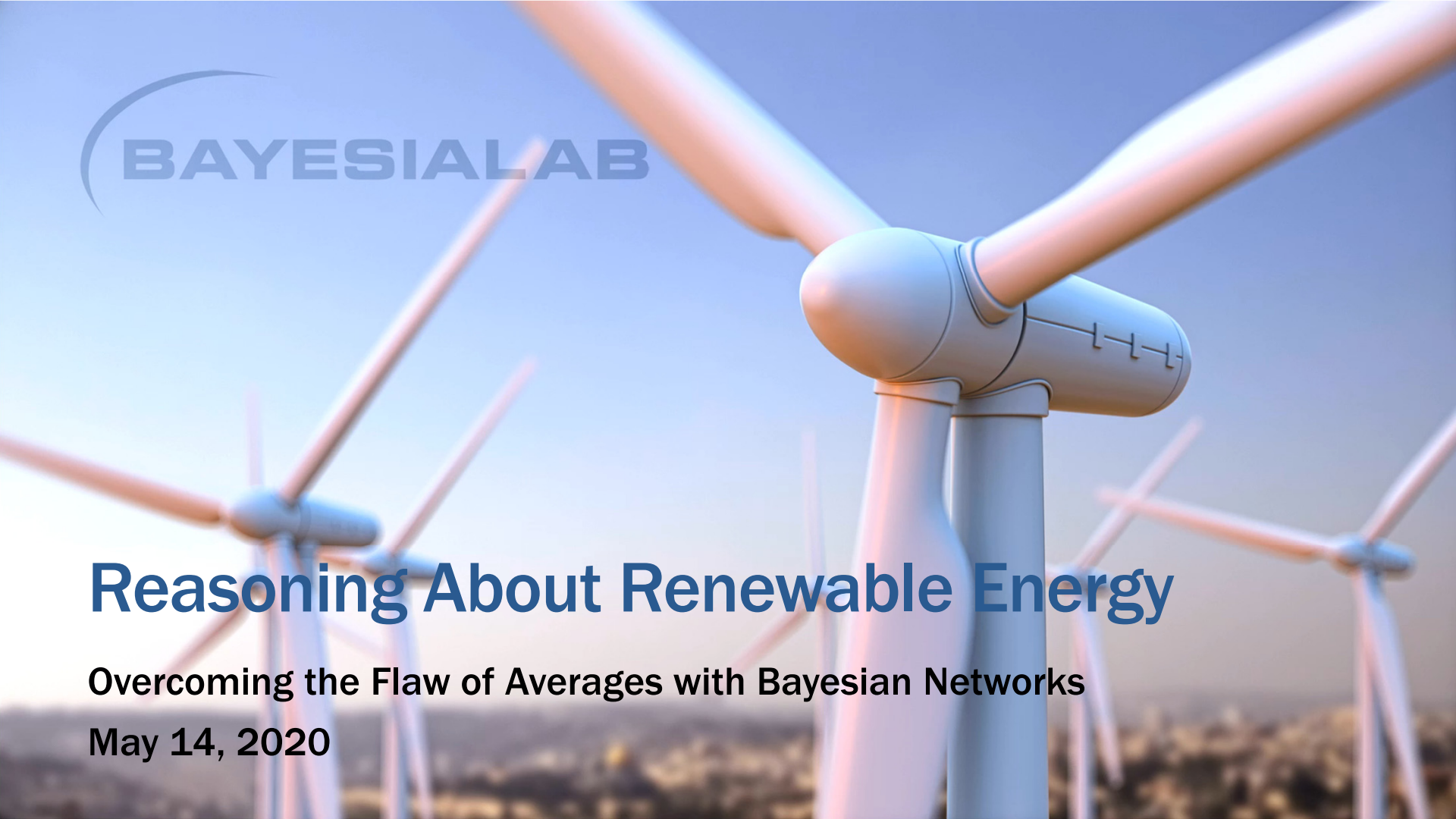


# Reasoning About Renewable Energy

## Overcoming the Flaw of Averages with Bayesian Networks

May 14, 2020

# Agenda

## Introduction & Resources

## Motivation & Objective

- Sun & wind: unlimited, free power?
- Reasoning under extreme uncertainty

## Analysis Workflow

- Machine-learning a Bayesian network from weather data
- Building a Bayesian network model from domain knowledge
- Simulating and evaluating scenarios

# Introduction

# BAYESIALAB


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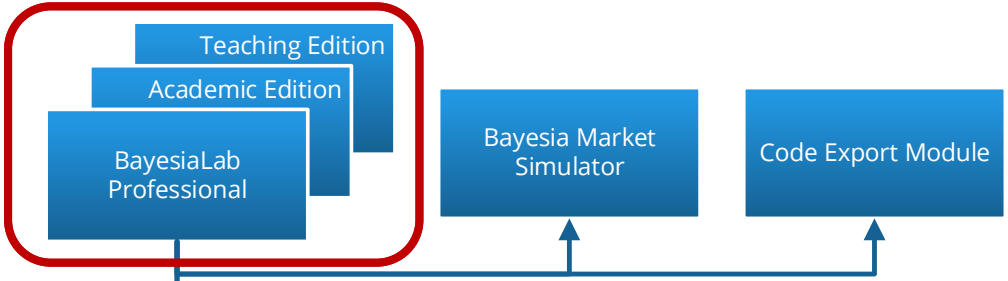
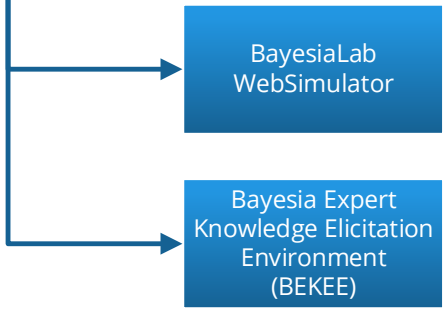
Professional
Bayesian Networks & BayesiaLab
A Practical Introduction for Researchers

BAYESIALAB

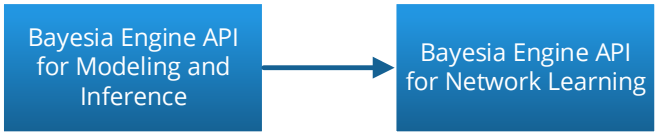
## Desktop Software




## Web Application



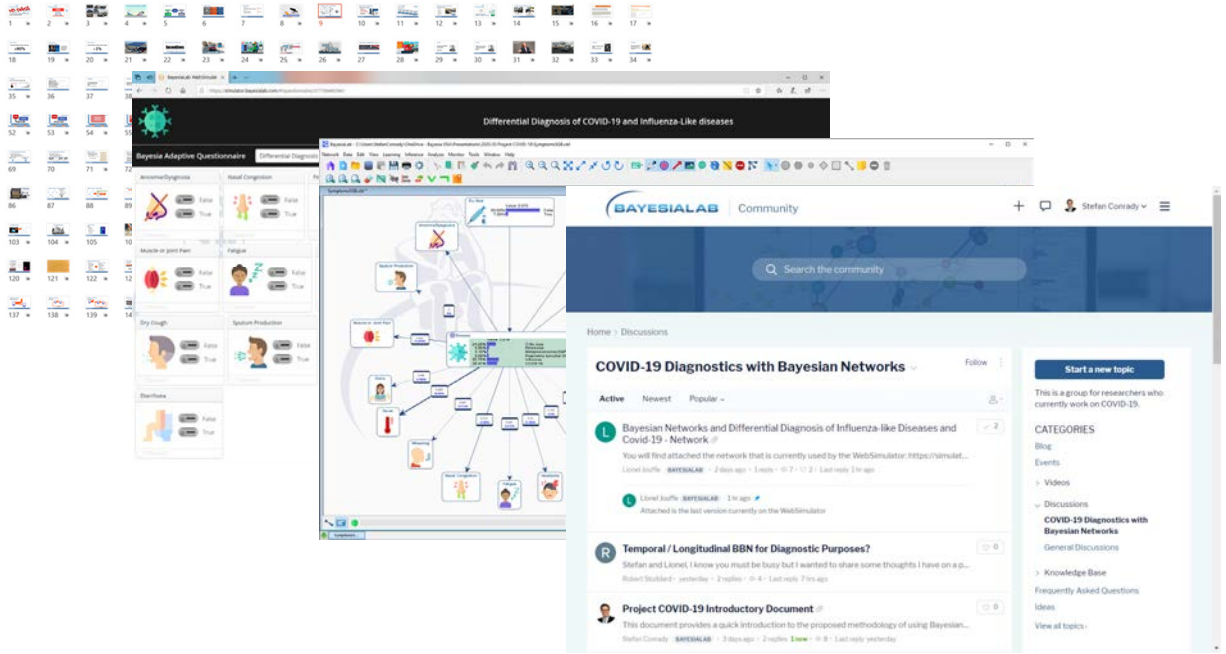

## API



# Resources

## Webinar Materials Available in the BayesiaLab Community

- Slides
- Network Model
- Webinar Recording
- Q&A



COVID-19 Diagnostics v

https://forum.bayesia.us/category/covid

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Question?
"Start a new topic"

Home > Discussions

## COVID-19 Diagnostics with Bayesian Networks

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Active Newest Popular

**Call for Expertise — Help Improve the COVID-19 Knowledge Base** 2

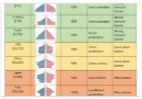
Please join our volunteer group of infectious disease specialists, clinicians, epidemiologists, biost...

Stefan Conrady BAYESIALAB · 4 days ago · 2 replies · 101 · 2 · Last reply 3 days ago

**Oral polio vaccine as infection control?** 2

Chinese study theorizes that oral polio vaccine can reduce probably of Covid19 in under-30 dem...

Kurt Schulzke · 4 days ago · 2 replies · 5 · 2 · Last reply 4 days ago



Start a new topic

This is a group for researchers who currently work on COVID-19.

CATEGORIES

- Blog
- Events
- Videos
- Discussions
  - **COVID-19 Diagnostics with Bayesian Networks**
  - General Discussions
- Knowledge Base
- Frequently Asked Questions
- Ideas

View all topics

Reasoning Under Uncer

https://forum.bayesia.us/t/q6hhach/reasoning-under-uncertainty-part-2-differential-diagnosis-of-covid-19

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Please see Part 1-4 of this webinar series

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# Reasoning Under Uncertainty (Part 2) — Differential Diagnosis of COVID-19

Updated 7 days ago


CONTENTS



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THE WALL STREET JOURNAL.

# U.S. Approves Giant Solar Project in Nevada

Gemini project will have capacity to power all Las Vegas homes

The Lake Las Vegas community of Henderson. The projec
power to cover the residential population of Las Vegas. CF
FOR THE WALL STREET JOURNAL

*By Timothy Puko*

May 11, 2020, 1:00 p.m. EDT

WASHINGTON—The Interior Department l
proval for what it says will be the largest sc
in the U.S., a $1 billion installation in Nevad

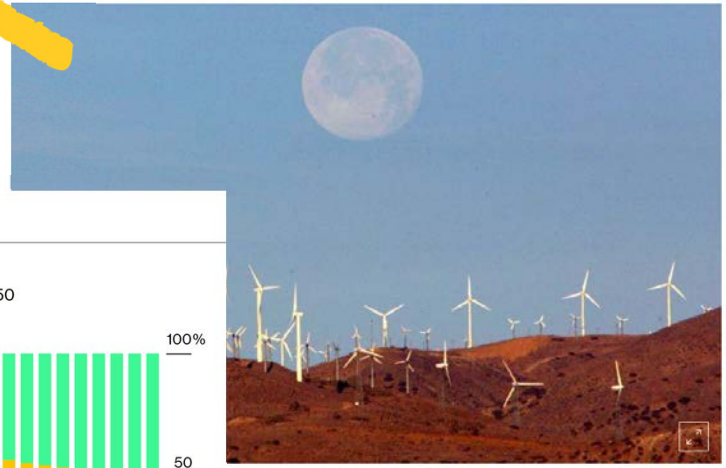
REUTERS

Business Markets World Politics TV More

ENVIRONMENT MAY 4, 2020 / 5:31 PM / 9 DAYS AGO

# Amid pandemic, U.S. renewable power sources have topped coal for 40 days

Nichola Groom 3 MIN READ



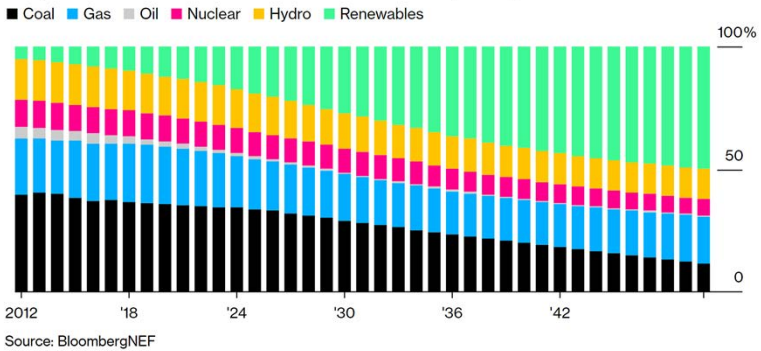
ind farm in the Mojave Desert in California, January 8,

city generated by renewable sources like solar, wind and hydro has
l power in the United States for a record 40 straight days, according
n U.S. government data released on Monday.

**Bloomberg**

**Power Shift**

Wind, solar and other renewables will account for half of all power by 2050

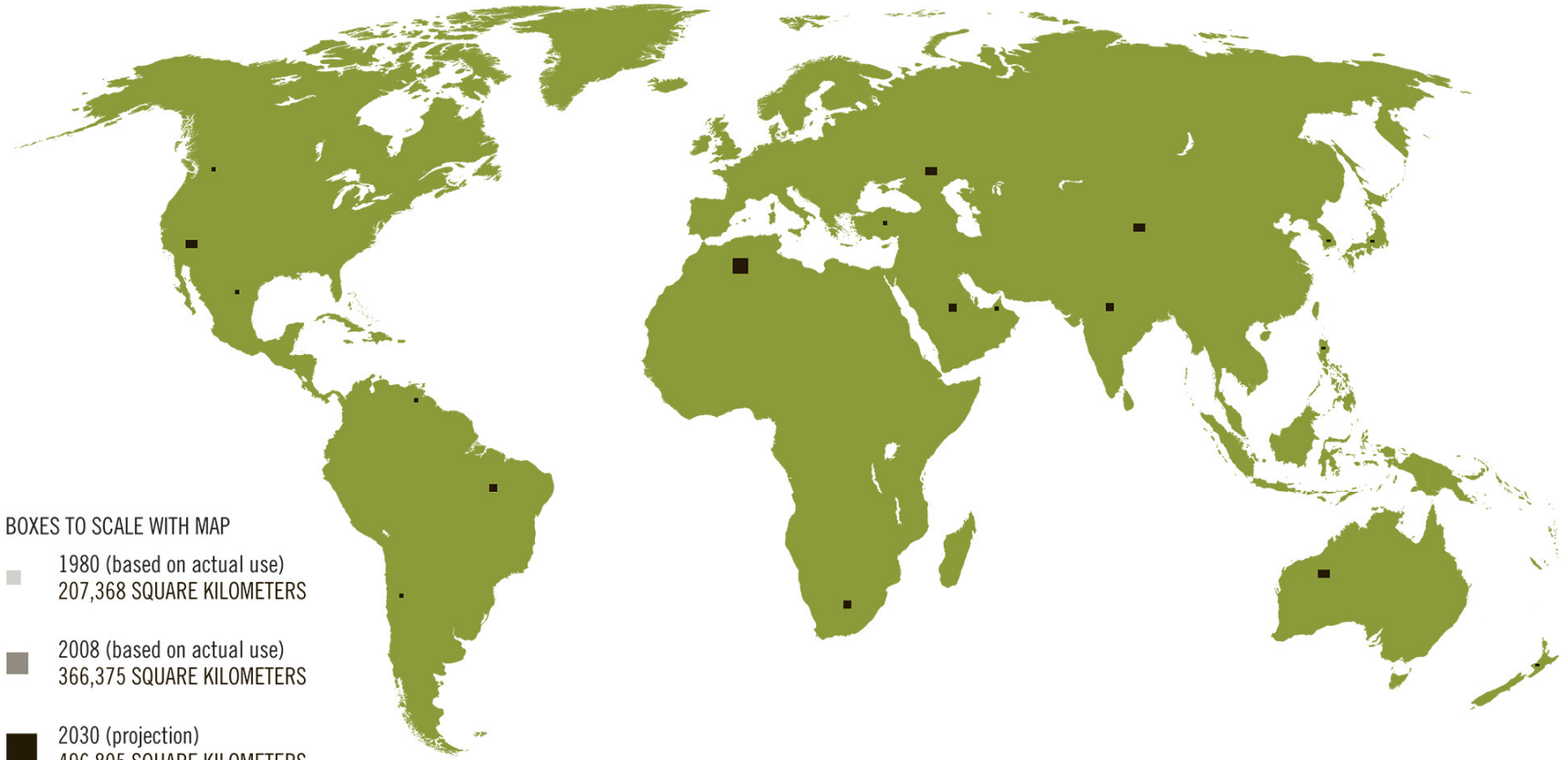



Source: BloombergNEF

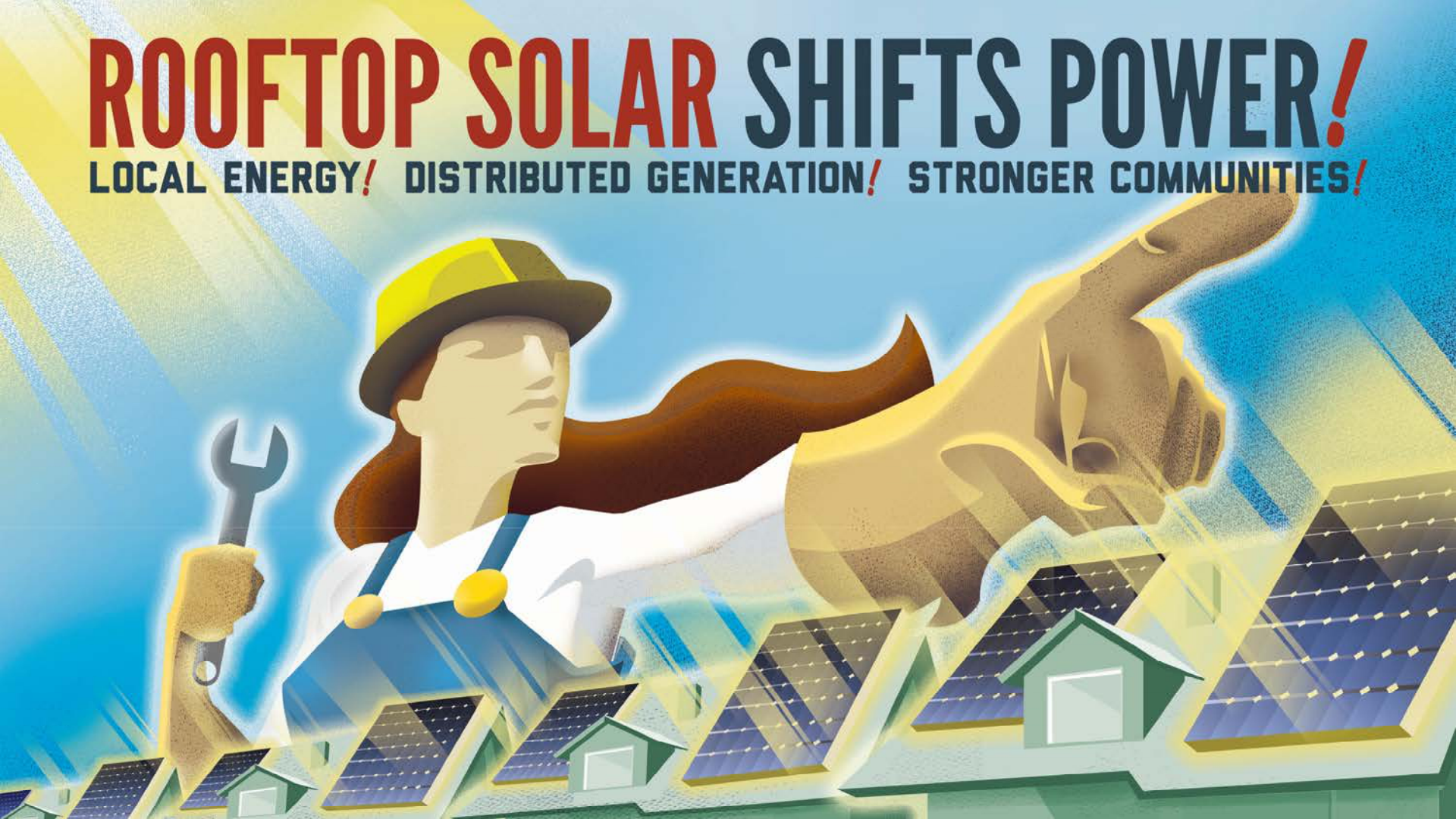
# SURFACE AREA REQUIRED TO POWER THE WORLD

## WITH ZERO CARBON EMISSIONS AND WITH SOLAR ALONE

www.landartgenerator.org

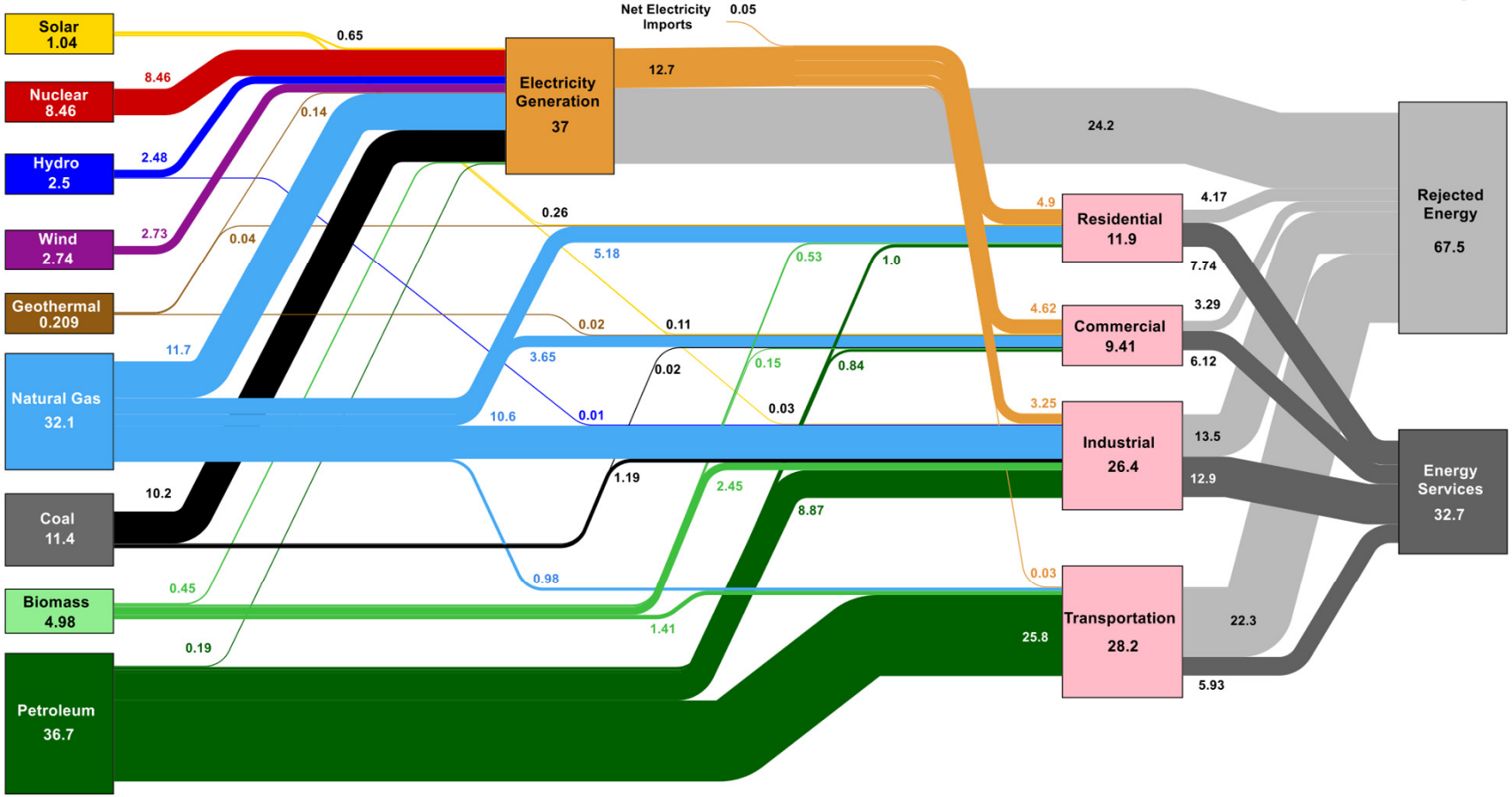



land art generator initiative


ROOFTOP SOLAR SHIFTS POWER!
LOCAL ENERGY! DISTRIBUTED GENERATION! STRONGER COMMUNITIES!

# Estimated U.S. Energy Consumption in 2019: 100.2 Quads

Lawrence Livermore National Laboratory

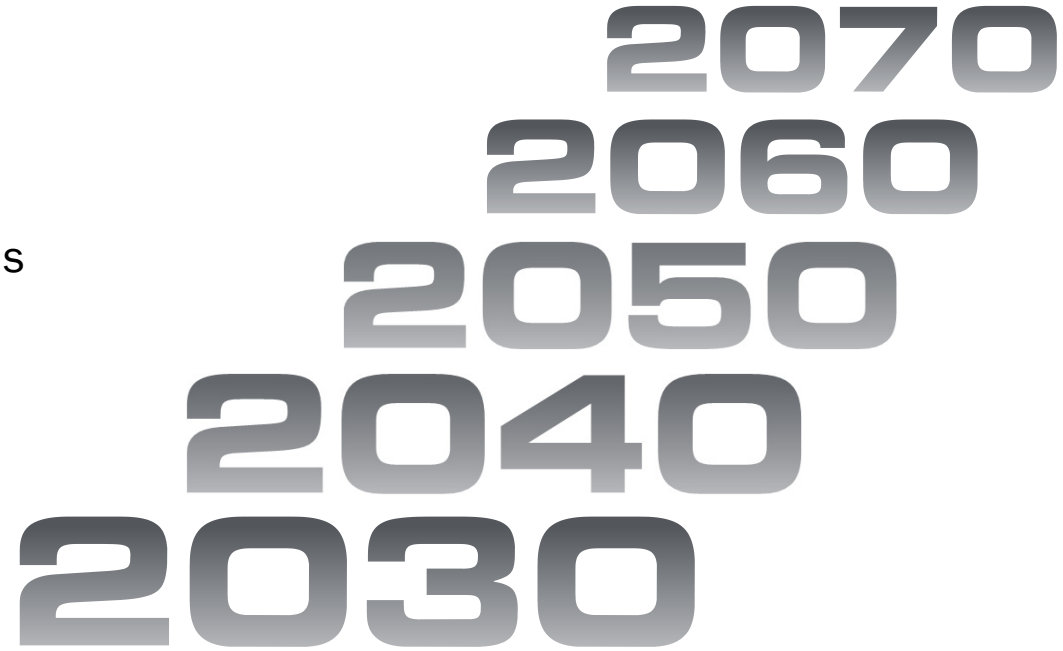



Source: LLNL March, 2020. Data is based on DOE/EIA MER (2019). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector and 49% for the industrial sector, which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

# Objective

## Reasoning About Renewable Energy

- Uncertainties regarding future…
  - Energy efficiency
  - Reliability
  - Government interventions
  - Emissions control
  - Manufacturing costs
  - Energy prices
  - Energy demand
  - Consumer behavior



# Objective

## Typical Questions

- Is it technically feasible to rely on renewables by 2050?
- How much fossil fuels will we still need if we triple the number of solar panels and wind turbines?
- Could batteries provide electricity at night and when there is no wind?
- How big would this batteries have to be?
- What's the risk of blackouts?
- Could we rely exclusively on renewables if electricity usage were cut in half?
- What would it take to shut down all fossil fuel-burning power plants?

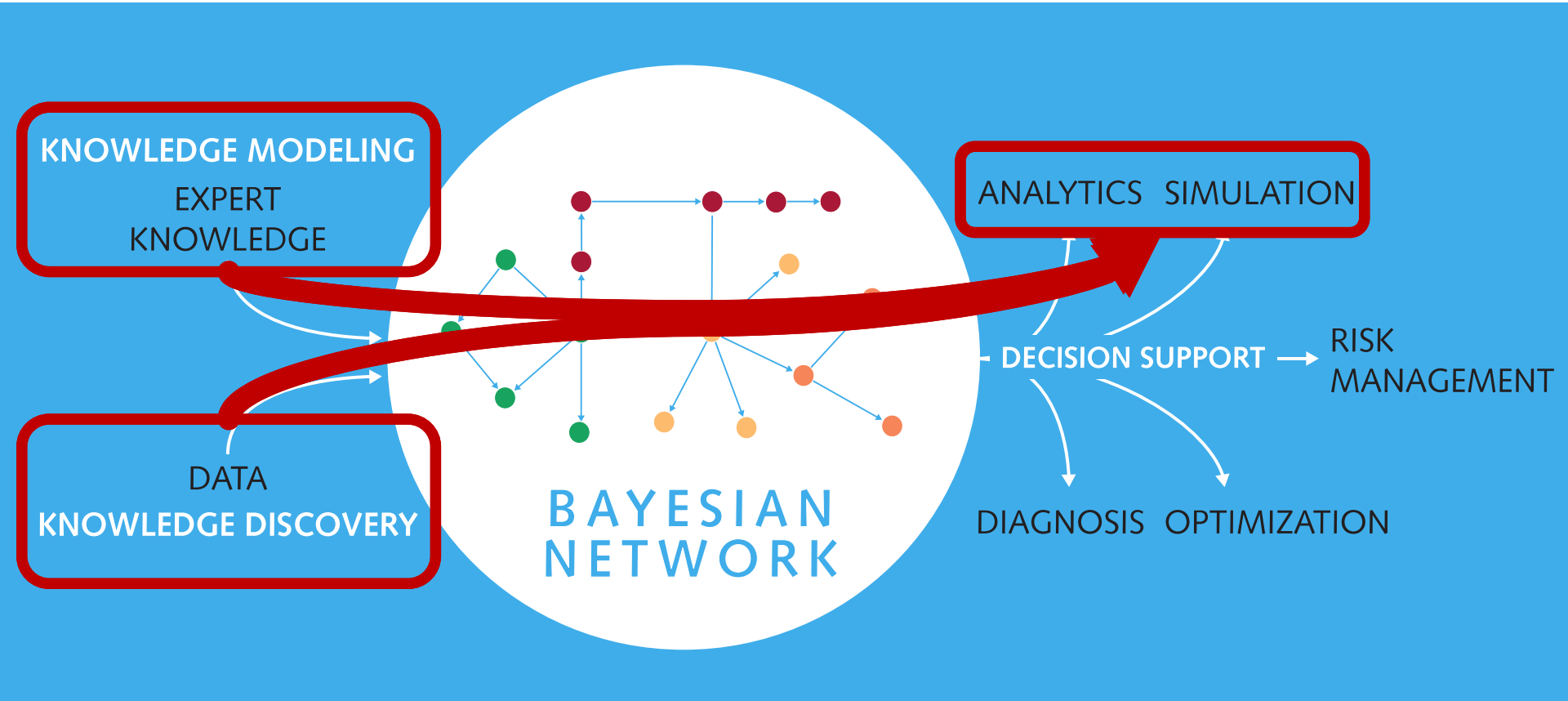
# Modeling the Problem Domain

## Model Requirements

- High level of abstraction, but scalable to include higher level of detail
- High-dimensional
- Probabilistic, to encode uncertainty
- Representing the system, not our reasoning about it
- Causal, to simulate decision/interventions
- Non-static
- Non-linear
- Compatible with expert knowledge and data
- Quick to simulate


SIMULATION
DEPT.

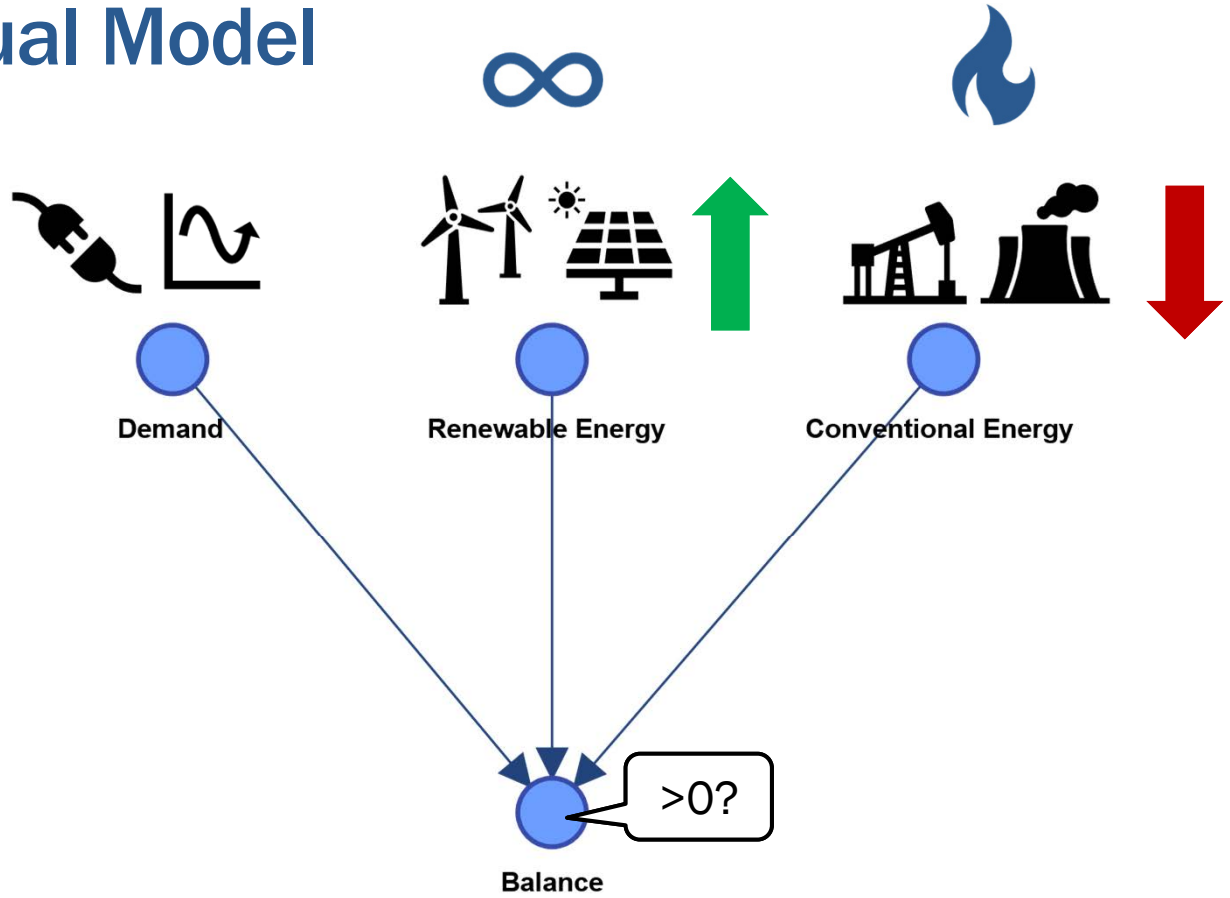
# Reasoning Framework: Bayesian Networks

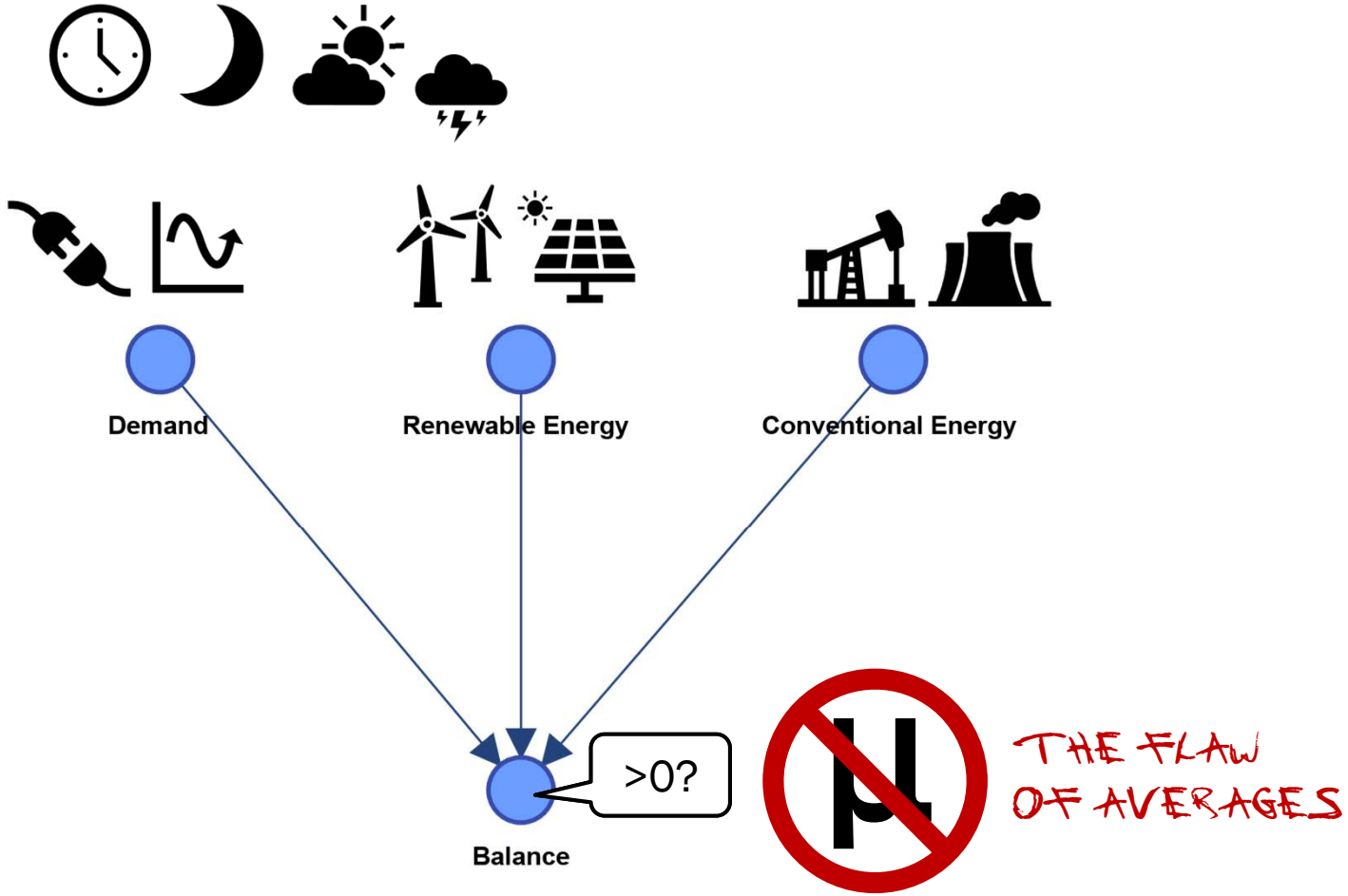


# Notes & Caveats

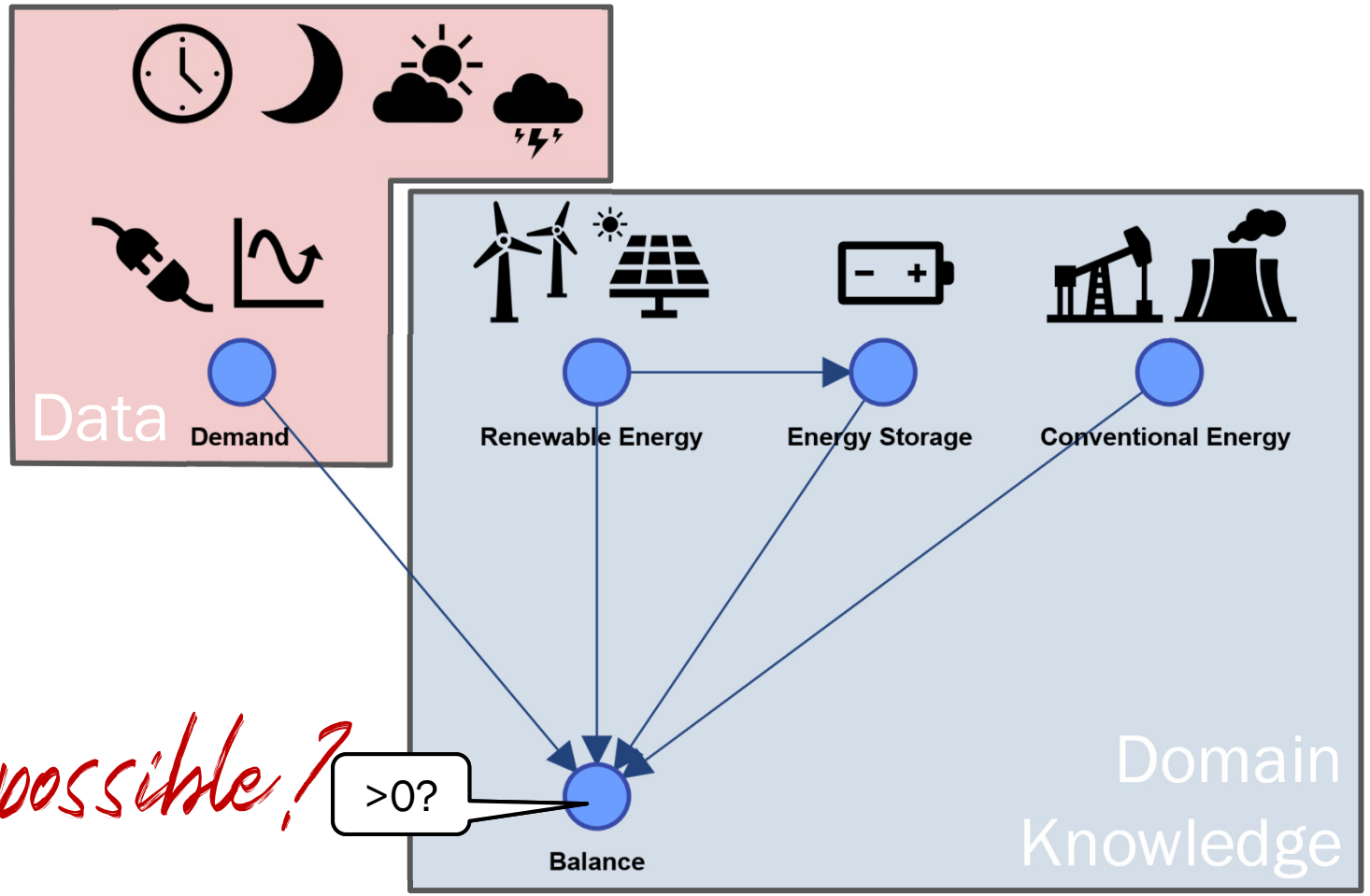
- While we are focusing on energy today, this example is prototypical for any type of “big picture” feasibility analysis.
- The proposed approach is not meant a substitute for detailed system analysis in a later planning process.
- Our model can be a tool for policy makers, investors, analysts, and auditors.
- In this webinar, we do not advocate any particular technology or recommend policies.
- All estimates shown in this webinar are meant to be realistic, but the exact numerical values are arbitrary.

# Conceptual Model



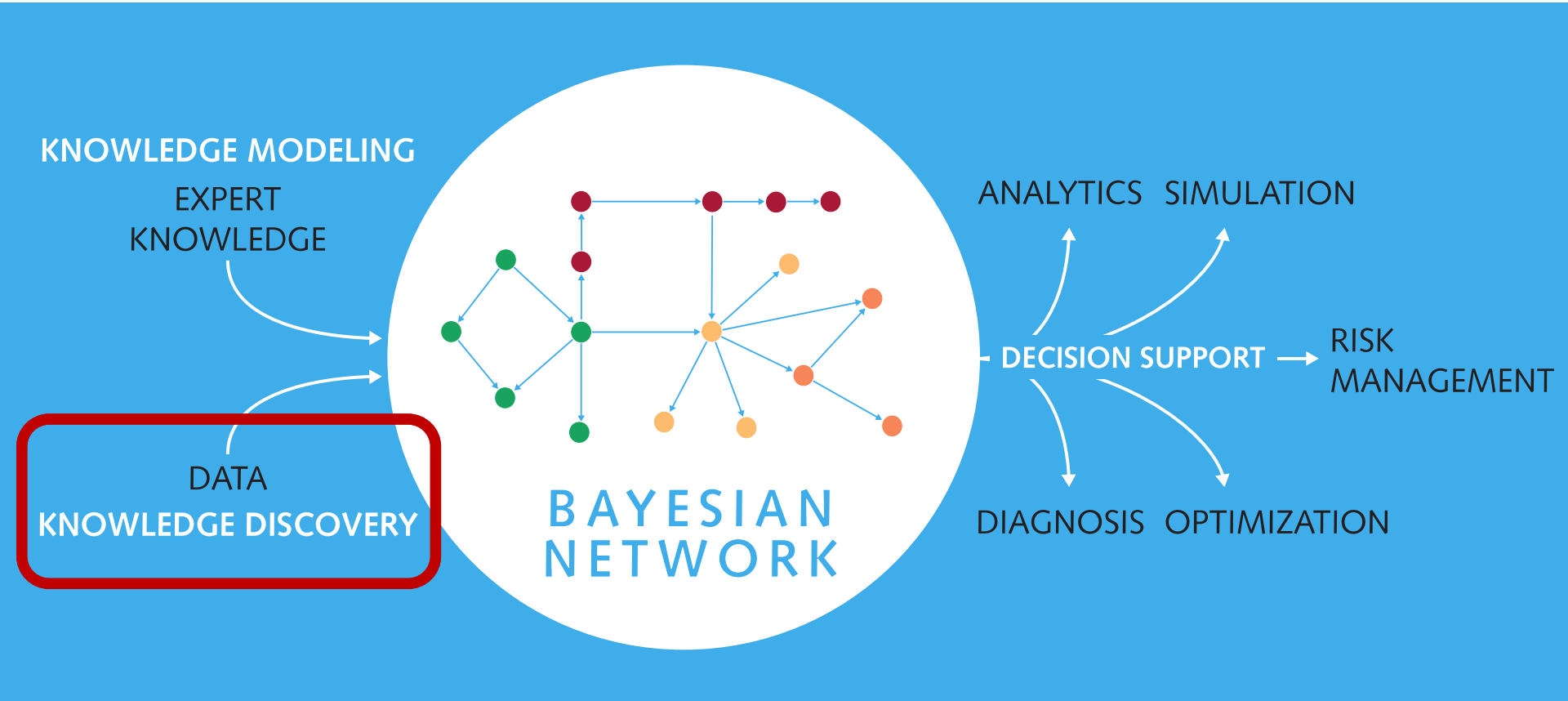

Demand
Renewable Energy
Conventional Energy
>0?
Balance
THE FLAW OF AVERAGES


ENERGY
STORAGE

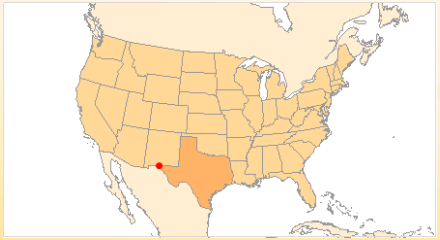



*Is this possible?*

# Reasoning Framework: Bayesian Networks

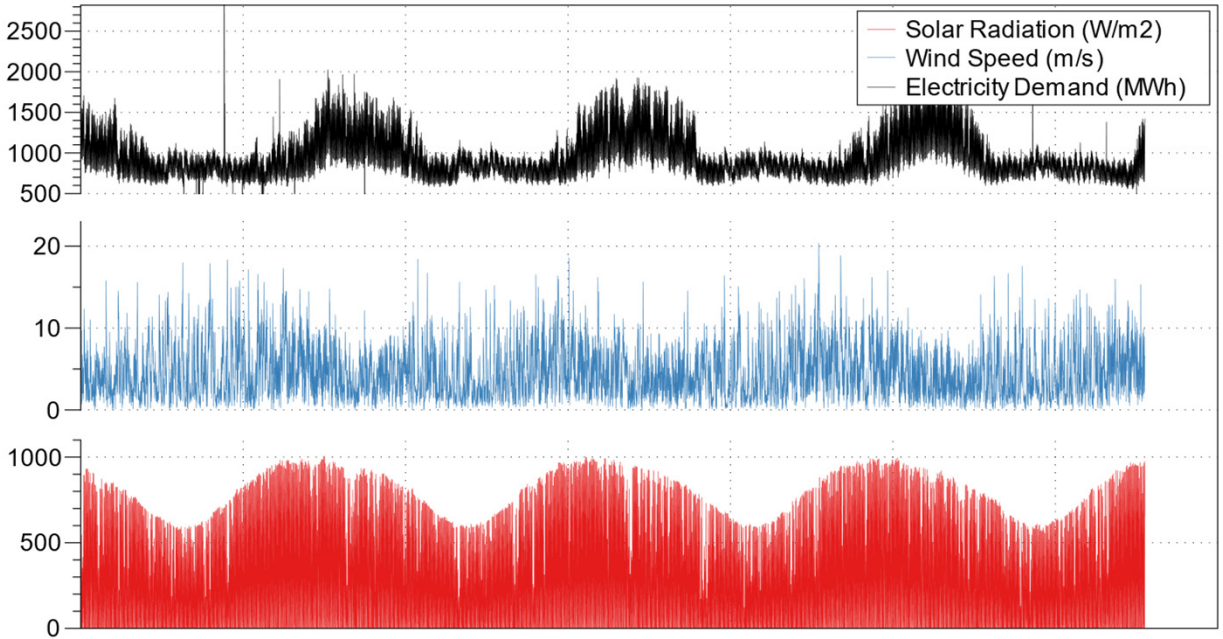


# EL PASO, TEXAS



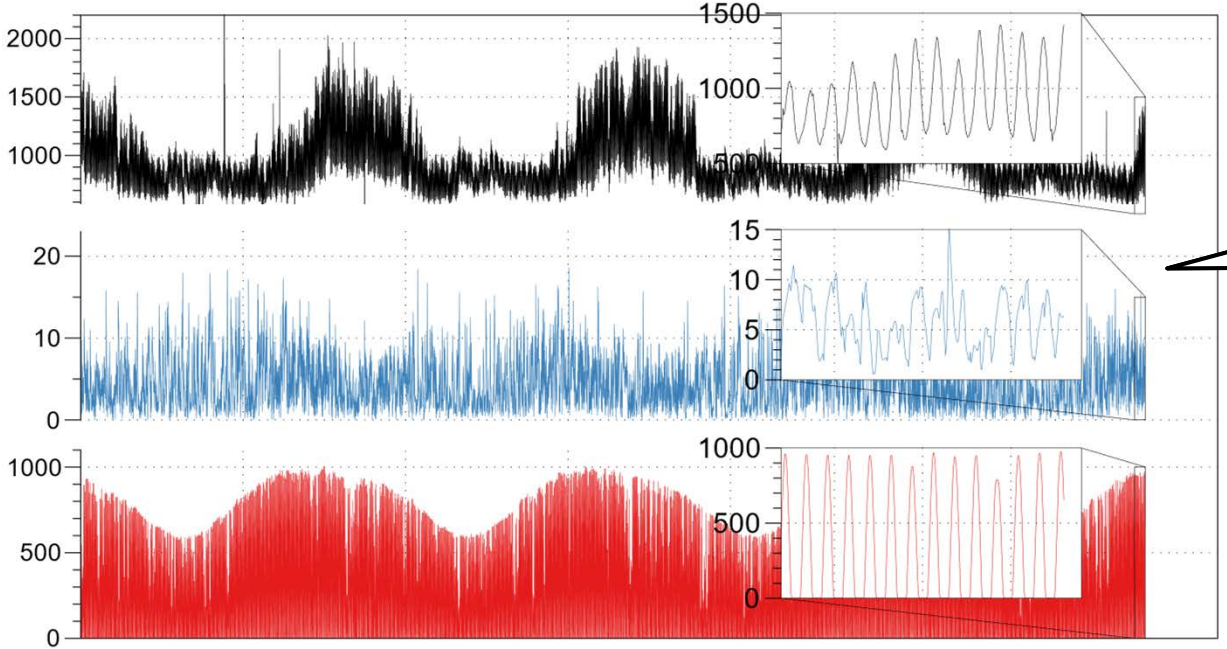
# El Paso, Texas

## Sun, Wind, and Electricity Demand Data (August 2016 – May 2020)



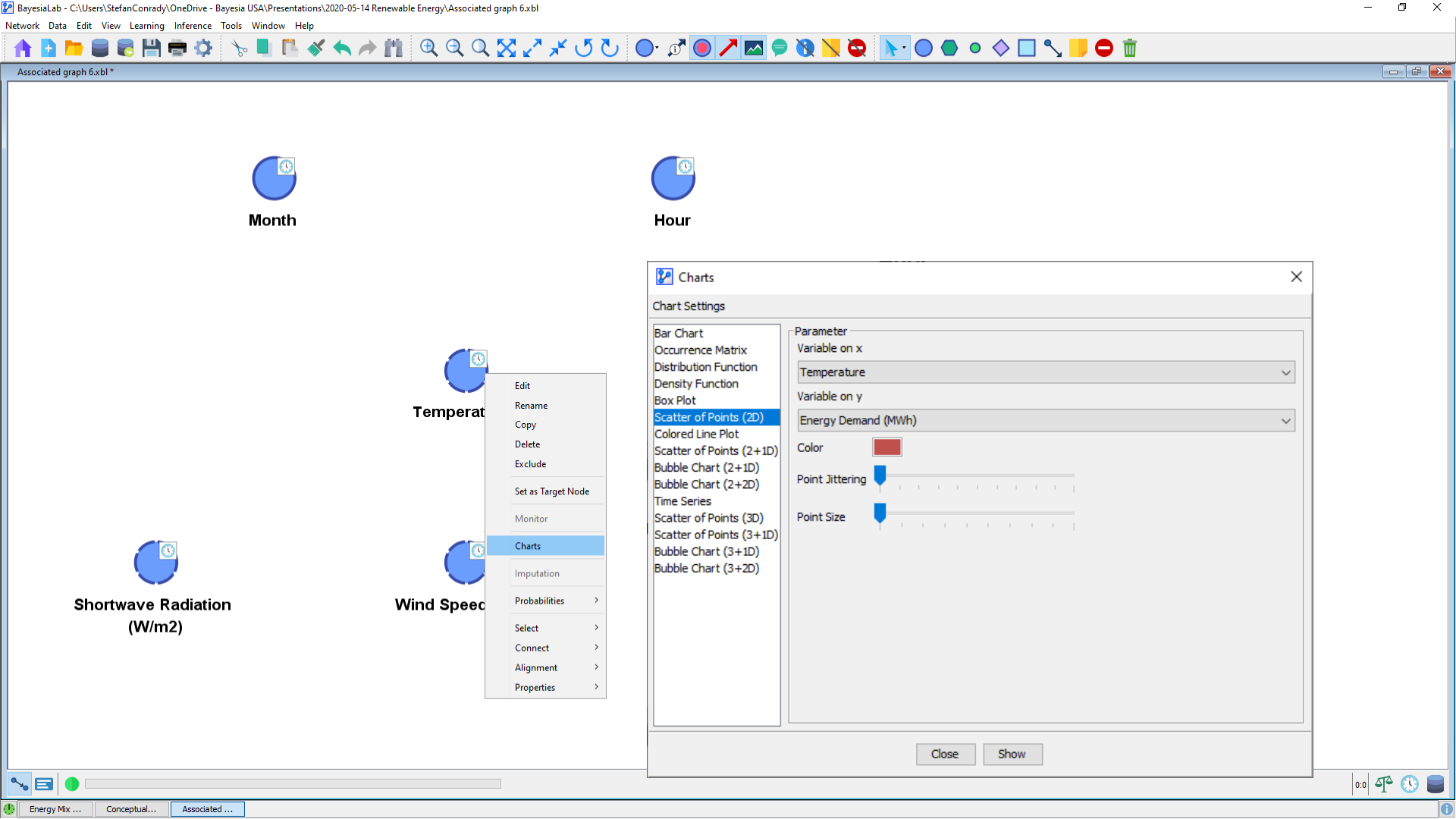
# El Paso, Texas

## Sun, Wind, and Electricity Demand Data (August 2016 – May 2020)




Hourly Data

# Joint Probability Distribution


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Presentations\2020-05-14 Renewable Energy\Associated graph 6.xbl
Network Data Edit View Learning Inference Tools Window Help
Associated graph 6.xbl *
Month
Hour
Temperat
Shortwave Radiation (W/m2)
Wind Speed
Edit
Rename
Copy
Delete
Exclude
Set as Target Node
Monitor
Charts
Imputation
Probabilities
Select
Connect
Alignment
Properties
Charts
Chart Settings
Bar Chart
Occurrence Matrix
Distribution Function
Density Function
Box Plot
Scatter of Points (2D)
Colored Line Plot
Scatter of Points (2+1D)
Bubble Chart (2+1D)
Bubble Chart (2+2D)
Time Series
Scatter of Points (3D)
Scatter of Points (3+1D)
Bubble Chart (3+1D)
Bubble Chart (3+2D)
Parameter
Variable on x
Temperature
Variable on y
Energy Demand (MWh)
Color
Point Jittering
Point Size
Close
Show
Energy Mix ...
Conceptual...
Associated ...

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Network Data Edit View Learning Inference Tools Window Help

Associated graph 6.xbl *

Scatter of Points (2D)

Displayed Points: 32758

x: 41.75
y: 1735

Energy Demand (MWh)

Temperature

Close Save

Scatter of Points (2D)

Displayed Points: 32453

x: 1791
y: 209

Shortwave Radiation (W/m2)

Energy Demand (MWh)

Close Save

Scatter of Points (2D)

Displayed Points: 32721

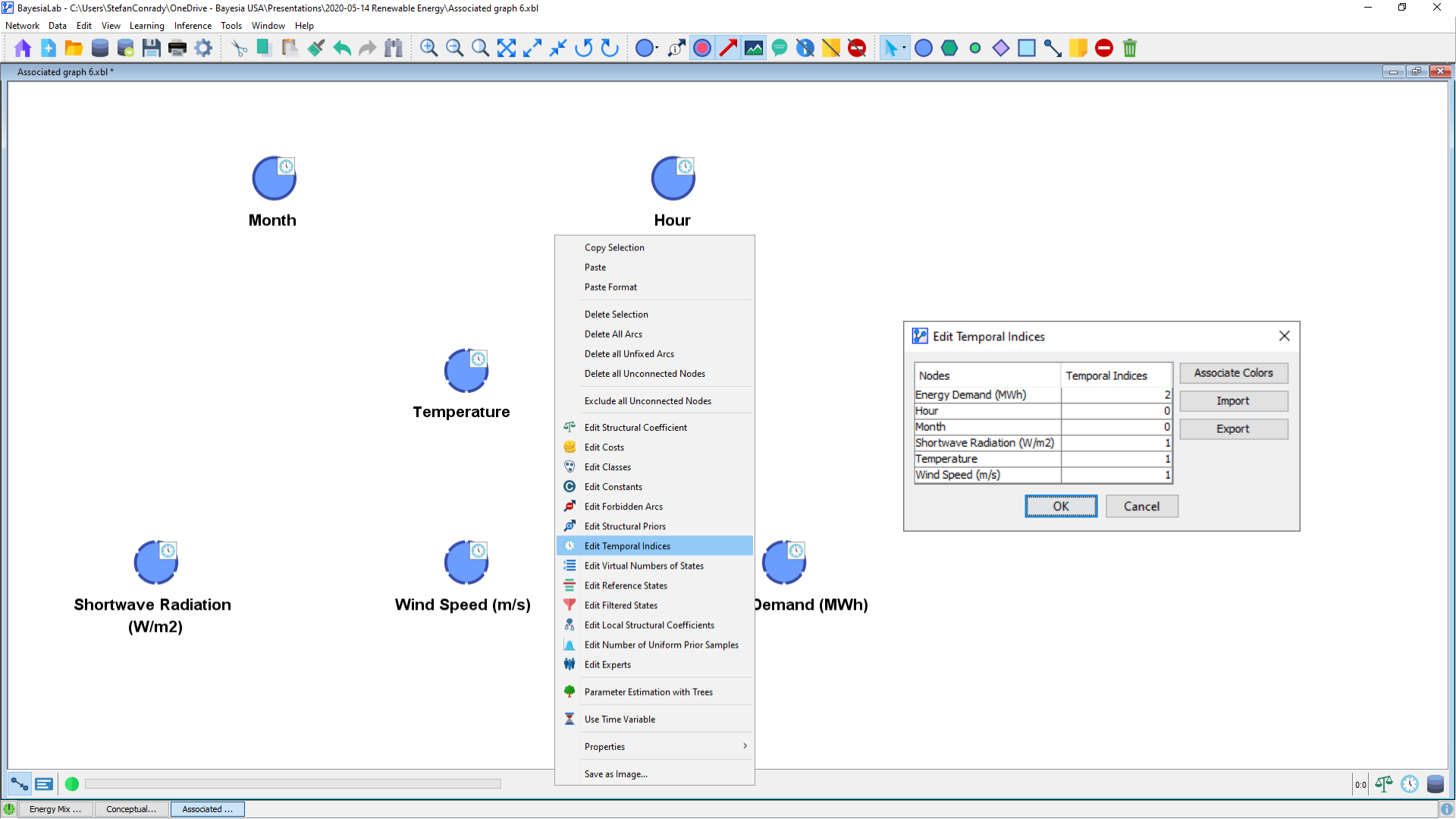
x: 1896.5
y: 12

Wind Speed (m/s)

Energy Demand (MWh)

Close Save

Energy Mix ... Conceptual... Associated ...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Network Data Edit View Learning Inference Tools Window Help
Associated graph 6.xbl *
Month
Hour
Temperature
Shortwave Radiation (W/m2)
Wind Speed (m/s)
Demand (MWh)
Copy Selection
Paste
Paste Format
Delete Selection
Delete All Arcs
Delete all Unfixed Arcs
Delete all Unconnected Nodes
Exclude all Unconnected Nodes
Edit Structural Coefficient
Edit Costs
Edit Classes
Edit Constants
Edit Forbidden Arcs
Edit Structural Priors
Edit Temporal Indices
Edit Virtual Numbers of States
Edit Reference States
Edit Filtered States
Edit Local Structural Coefficients
Edit Number of Uniform Prior Samples
Edit Experts
Parameter Estimation with Trees
Use Time Variable
Properties
Save as Image...
Edit Temporal Indices
Nodes
Temporal Indices
Energy Demand (MWh) 2
Hour 0
Month 0
Shortwave Radiation (W/m2) 1
Temperature 1
Wind Speed (m/s) 1
Associate Colors
Import
Export
OK
Cancel
Energy Mix ...
Conceptual...
Associated ...

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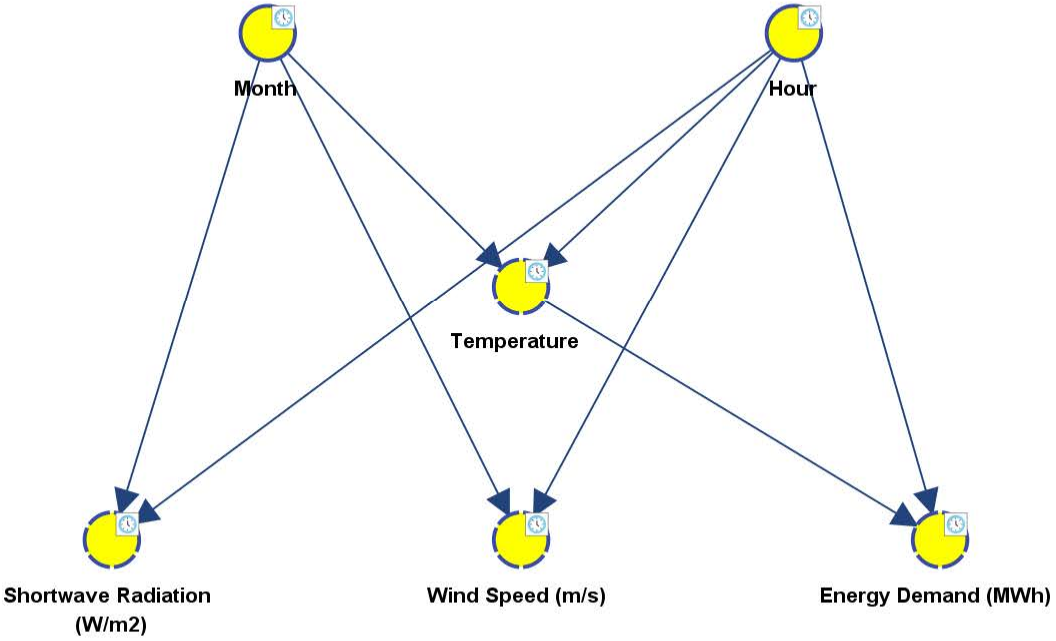
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help

Associated graph 5.xbl




Joint Probability: 100.00%
Log-Loss: 0
Cases: 32,759
Total Value: 1,220.121
Mean Value: 203.353

Energy Demand (MWh)
Mean: 951.066 Dev: 262.513
Value: 949.916

| | |
|---|---|
| 19.53% | <=741 |
| 28.98% | <=869 |
| 21.57% | <=992 |
| 11.08% | <=1150 |
| 8.26% | <=1349 |
| 6.86% | <=1579 |
| 3.72% | >1579 |

Month
Mean: 6.546 Dev: 3.558
Value: 6.546

| | |
|---|---|
| 9.08% | 1 |
| 8.28% | 2 |
| 9.08% | 3 |
| 8.79% | 4 |
| 7.09% | 5 |
| 6.59% | 6 |
| 6.81% | 7 |
| 8.52% | 8 |
| 8.79% | 9 |
| 9.08% | 10 |
| 8.79% | 11 |
| 9.08% | 12 |

Temperature
Mean: 19.124 Dev: 9.577
Value: 19.124

| | |
|---|---|
| 7.57% | <=5.102 |
| 16.18% | <=11.222 |
| 17.07% | <=16.452 |
| 17.53% | <=21.662 |
| 16.82% | <=26.732 |
| 15.05% | <=32.082 |
| 9.79% | >32.082 |

Hour
Mean: 11.500 Dev: 6.922
Value: 11.500

| | |
|---|---|
| 4.17% | 0 |
| 4.17% | 1 |
| 4.17% | 2 |
| 4.17% | 3 |
| 4.17% | 4 |
| 4.17% | 5 |
| 4.17% | 6 |
| 4.17% | 7 |
| 4.17% | 8 |
| 4.17% | 9 |
| 4.17% | 10 |
| 4.17% | 11 |
| 4.17% | 12 |
| 4.17% | 13 |
| 4.17% | 14 |
| 4.17% | 15 |
| 4.17% | 16 |
| 4.17% | 17 |
| 4.17% | 18 |
| 4.17% | 19 |
| 4.17% | 20 |
| 4.17% | 21 |
| 4.17% | 22 |
| 4.17% | 23 |

Shortwave Radiation (W/m2)
Mean: 228.417 Dev: 297.704
Value: 228.419

| | |
|---|---|
| 47.13% | <=0 |
| 6.49% | <=65.86 |
| 7.65% | <=203.81 |
| 8.90% | <=361.34 |
| 8.59% | <=522.43 |
| 9.19% | <=678.18 |
| 6.71% | <=826.81 |
| 5.34% | >826.81 |

Wind Speed (m/s)
Mean: 4.616 Dev: 3.083
Value: 4.616

| | |
|---|---|
| 6.58% | <=1 |
| 30.24% | <=2.857 |
| 30.60% | <=5.714 |
| 20.76% | <=8.571 |
| 8.98% | <=11.429 |
| 2.20% | <=14.286 |
| 0.54% | <=17.143 |
| 0.10% | >17.143 |

Energy Mix ... Conceptual... Associated ...

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Network Data Edit View Learning Inference Analysis Monitor

Associated graph 5.xbl

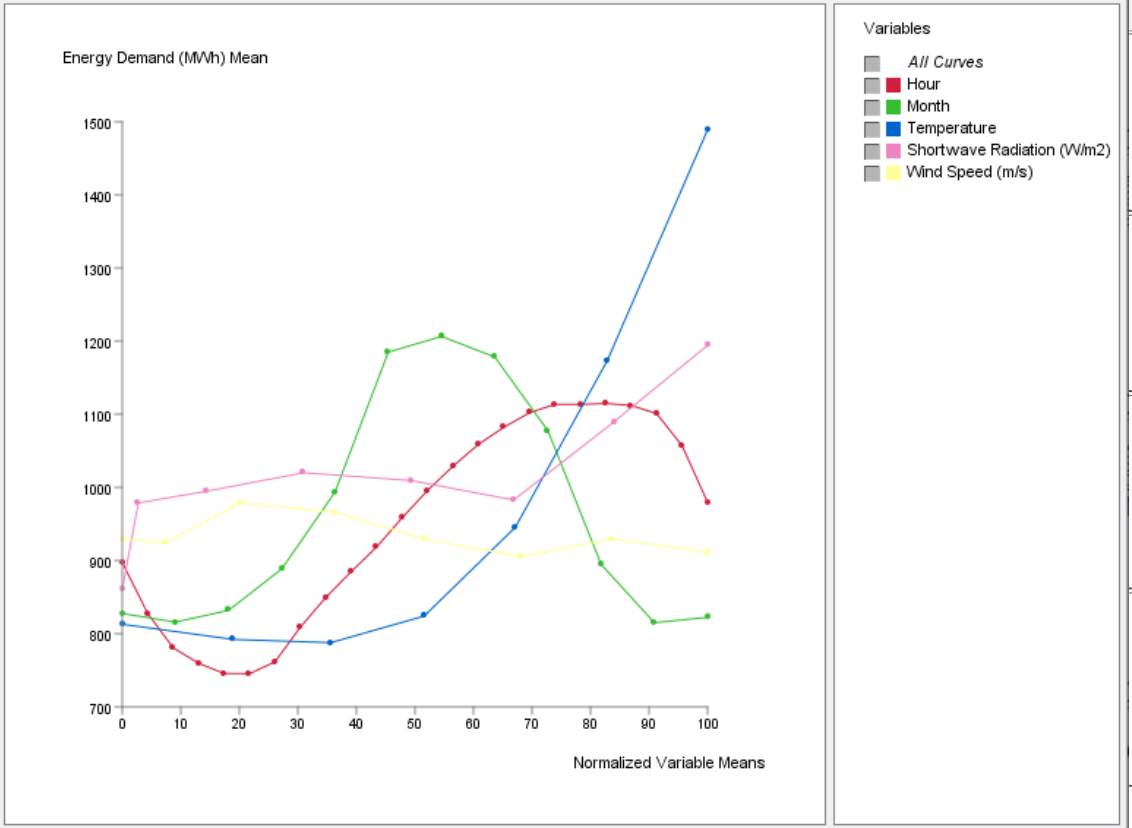
Month

Shortwave Radiation (W/m2)

Energy Mix ... Conceptual... Associated ...

## Target Mean Analysis

Node:
x:
y:




Close Save

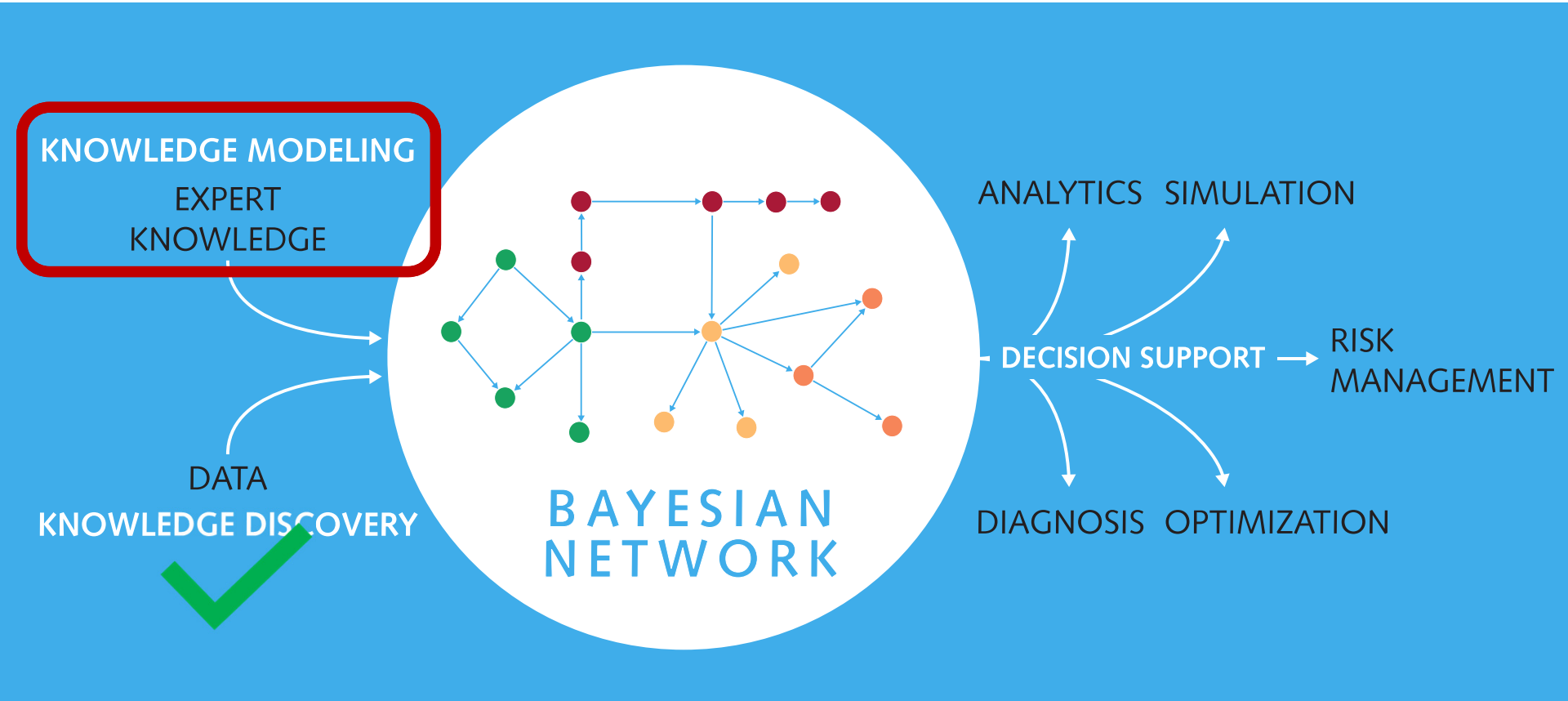
Month
Mean: 6.546 Dev: 3.558
Value: 6.546

| | |
|---|---|
| 9.08% | 1 |
| 8.28% | 2 |
| 9.08% | 3 |
| 8.79% | 4 |
| 7.09% | 5 |
| 6.59% | 6 |
| 6.81% | 7 |
| 8.52% | 8 |
| 8.79% | 9 |
| 9.08% | 10 |
| 8.79% | 11 |
| 9.08% | 12 |

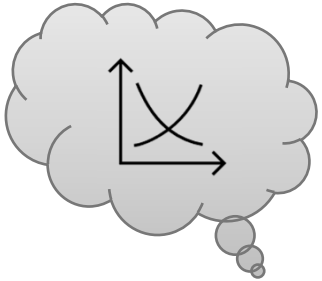
Hour
Mean: 11.500 Dev: 6.922
Value: 11.500

| | |
|---|---|
| 4.17% | 0 |
| 4.17% | 1 |
| 4.17% | 2 |
| 4.17% | 3 |
| 4.17% | 4 |
| 4.17% | 5 |
| 4.17% | 6 |
| 4.17% | 7 |
| 4.17% | 8 |
| 4.17% | 9 |
| 4.17% | 10 |
| 4.17% | 11 |
| 4.17% | 12 |
| 4.17% | 13 |
| 4.17% | 14 |
| 4.17% | 15 |
| 4.17% | 16 |
| 4.17% | 17 |
| 4.17% | 18 |
| 4.17% | 19 |
| 4.17% | 20 |
| 4.17% | 21 |
| 4.17% | 22 |
| 4.17% | 23 |

# Reasoning Framework: Bayesian Networks

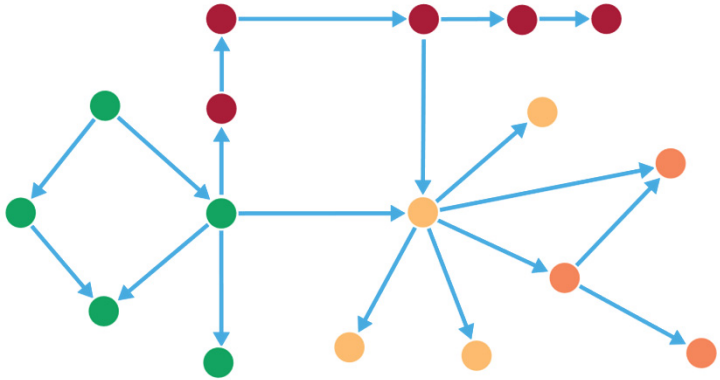


# Domain Knowledge



$$P_w = \frac{1}{2}\rho A v^3$$

Theoretical Knowledge



# Domain Knowledge

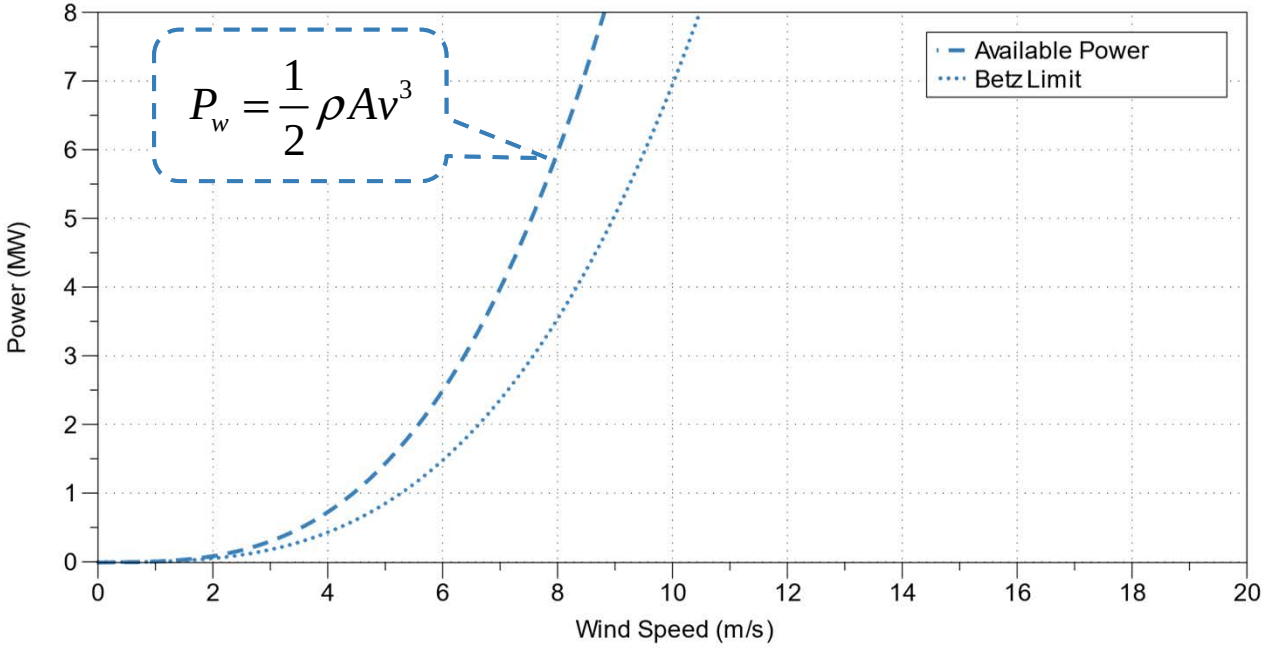
## Units

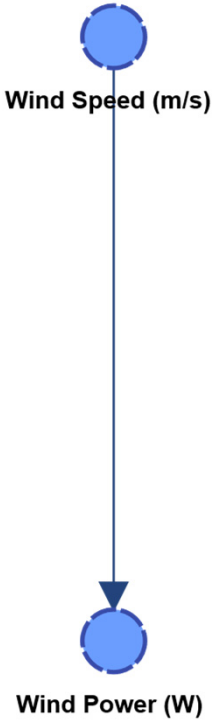
- Speed: m/s
- Power: MW
- Energy: MWh
- Power Density: W/m2
- Energy Density: MWh/t
- Temperature: ° Celsius

All Metric Units!

# Domain Knowledge

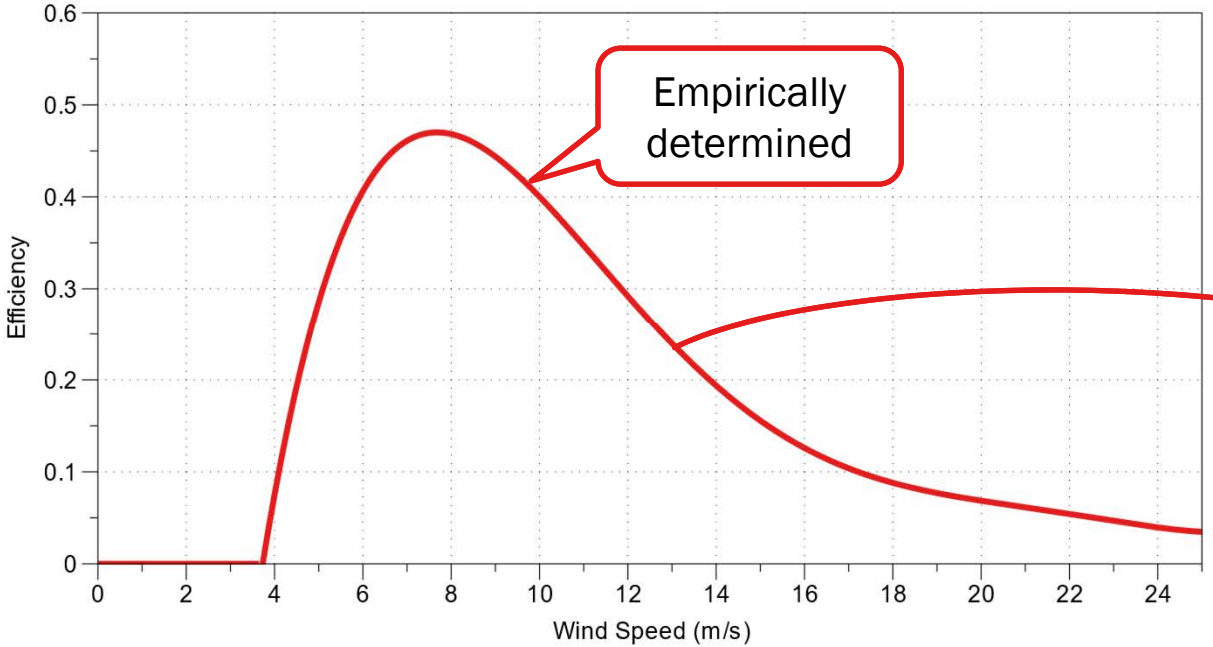
## Available Wind Energy

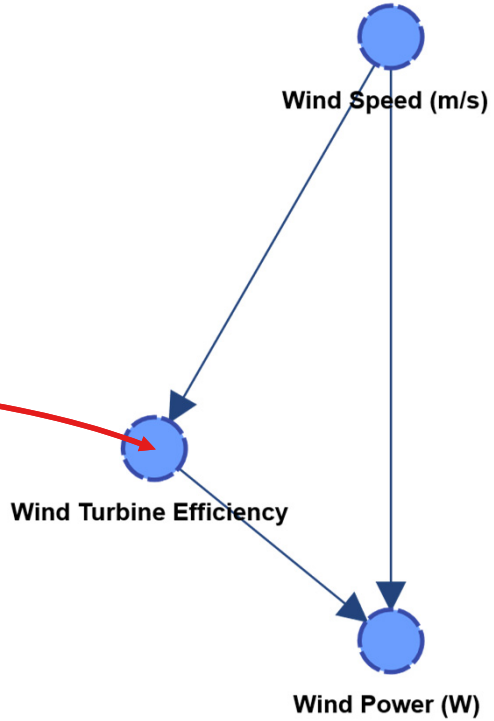


# Domain Knowledge

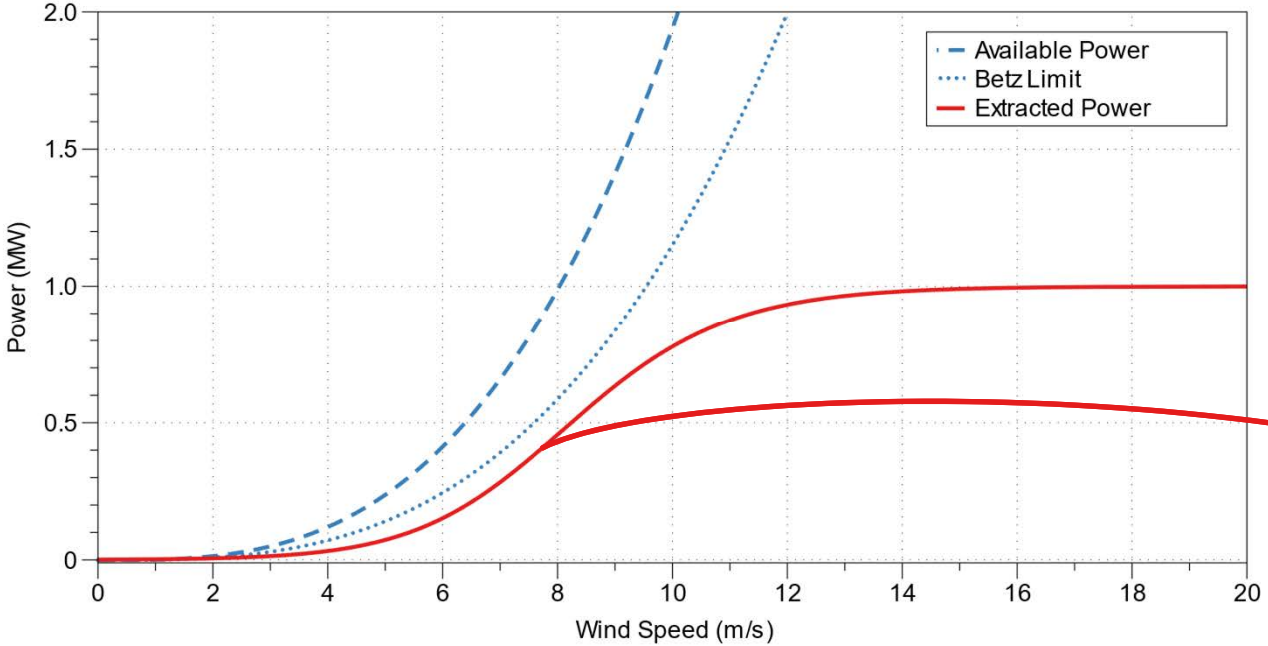
## Wind Turbine Efficiency

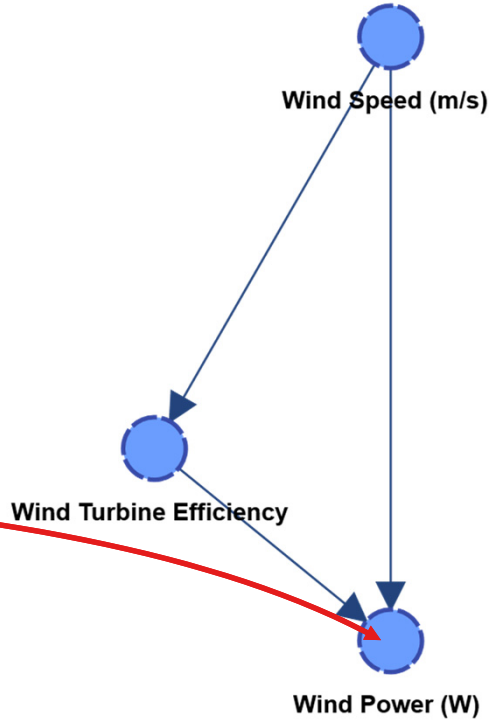


# Domain Knowledge

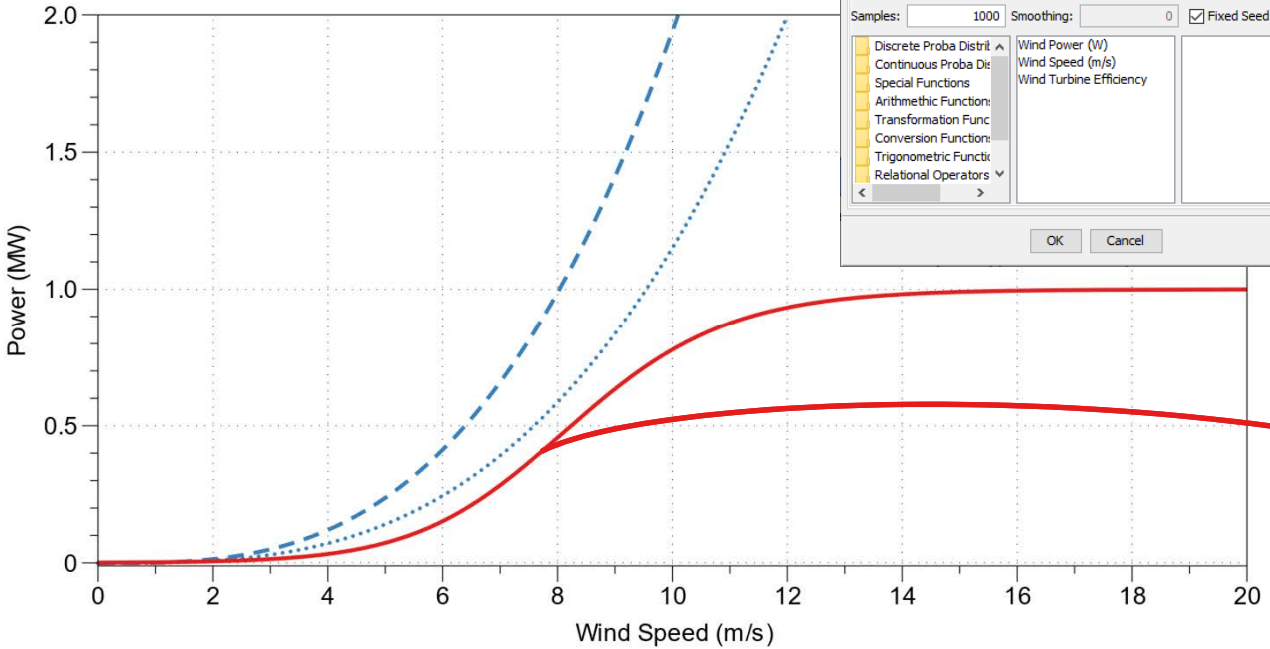
## Wind Energy

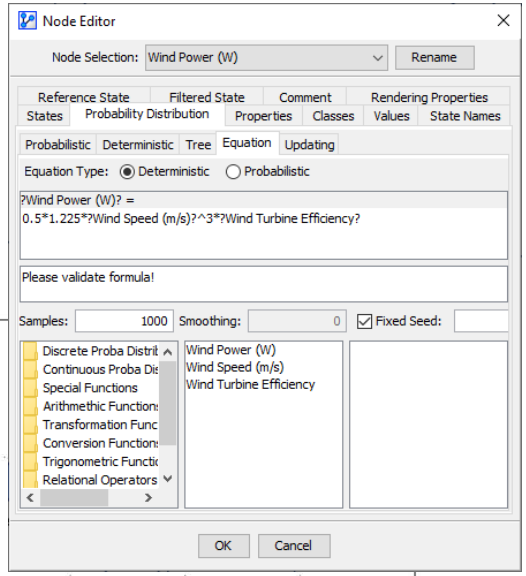


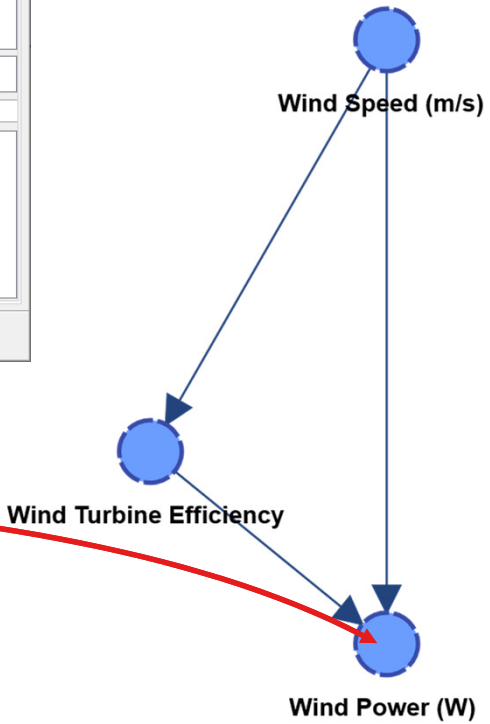



# Domain Knowledge

## Wind Energy

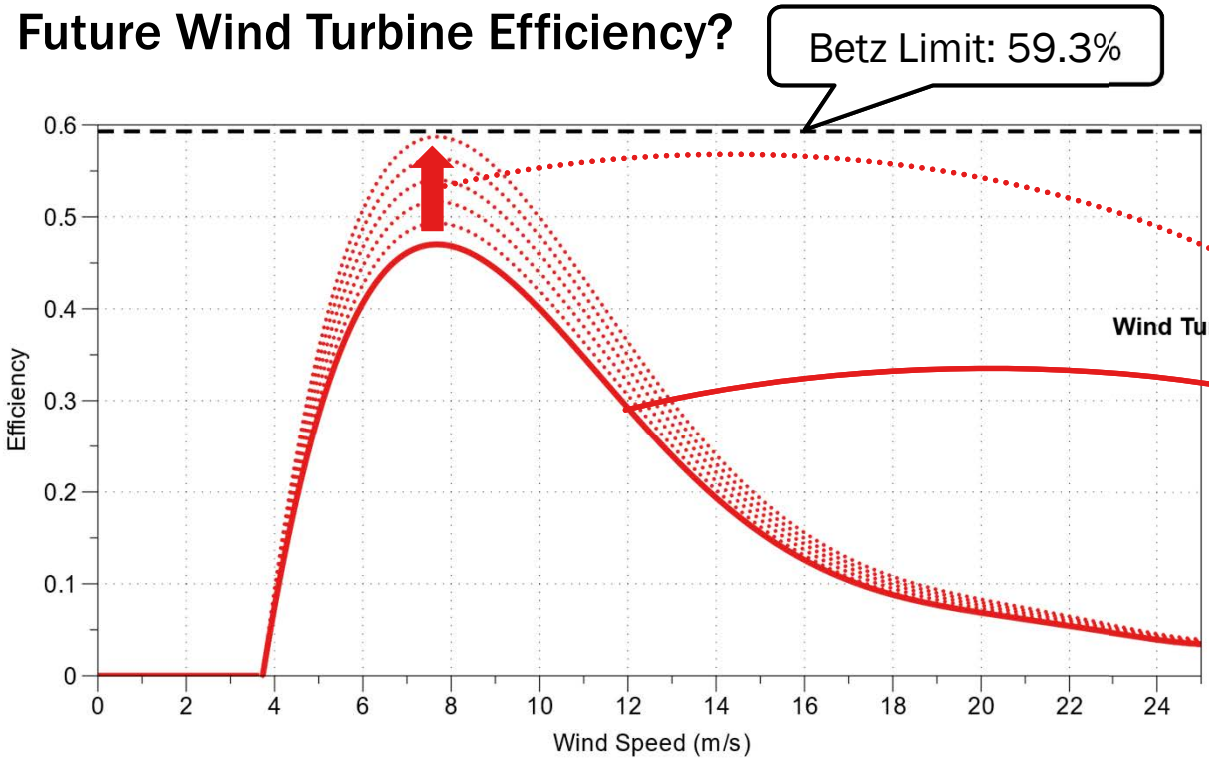


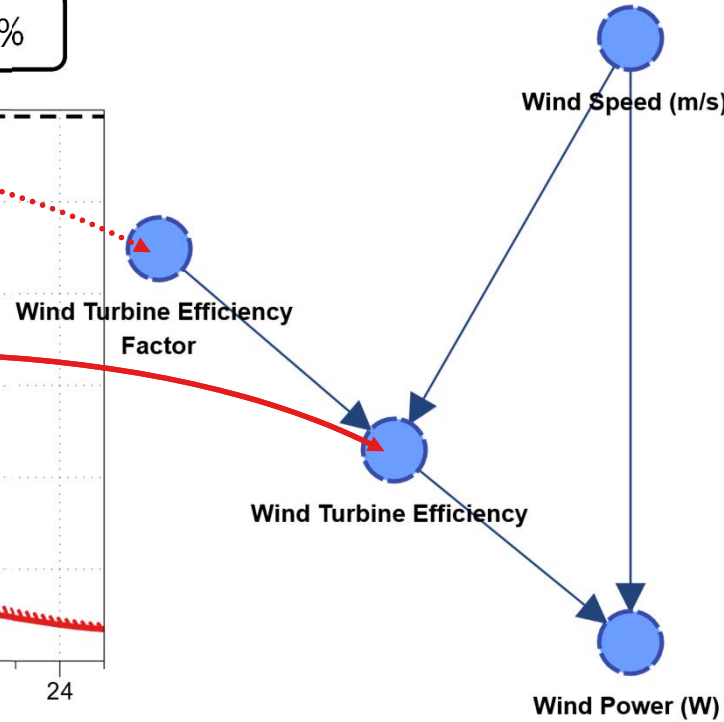



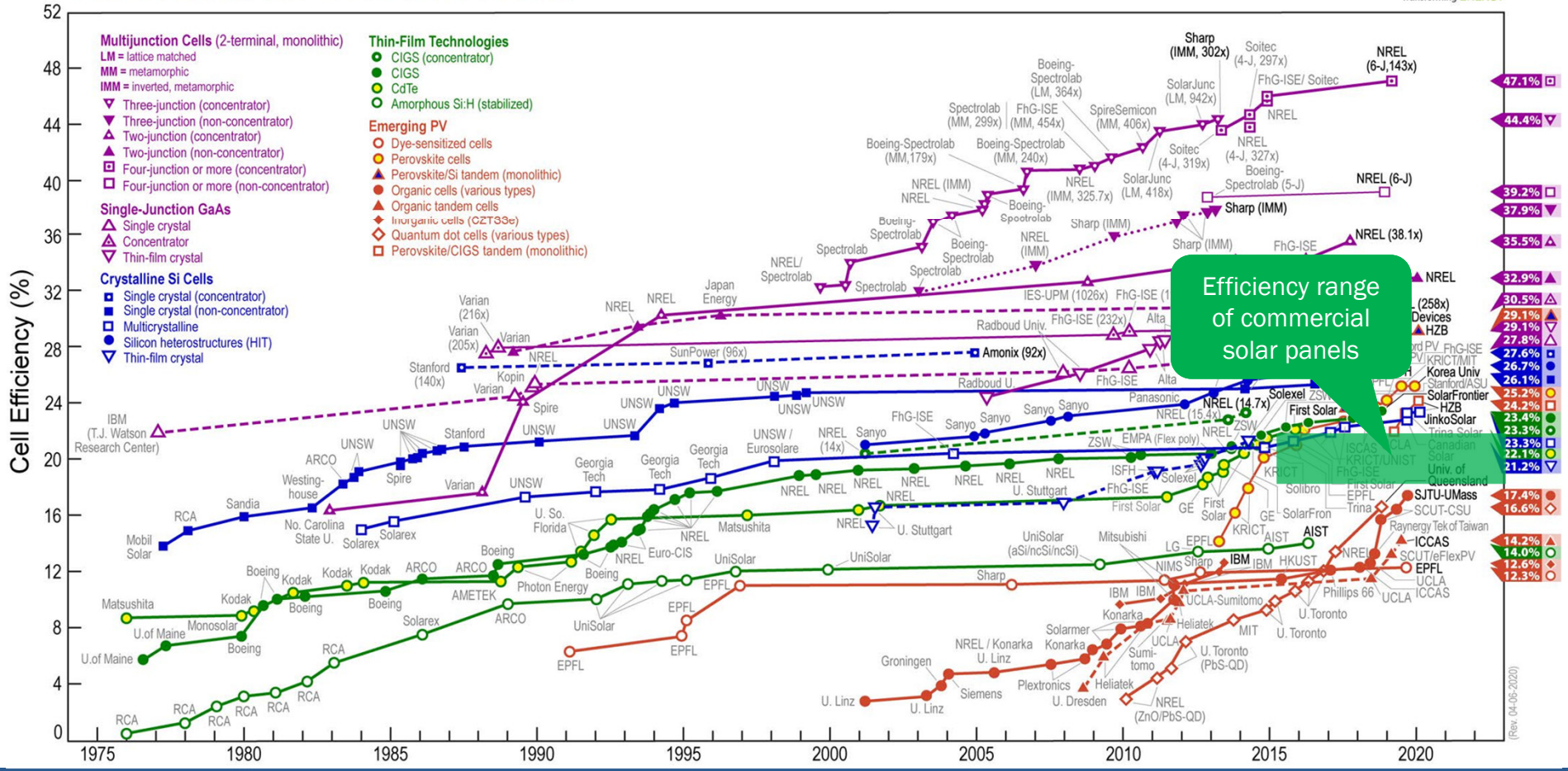
# Domain Knowledge

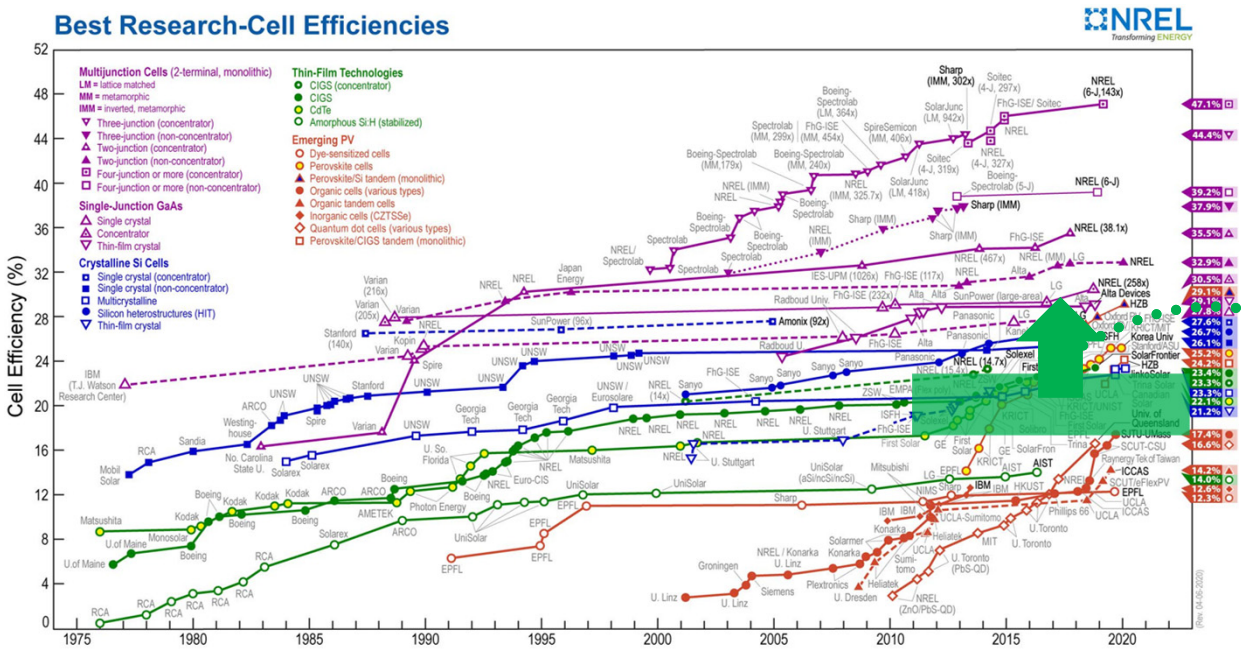
## Future Wind Turbine Efficiency?

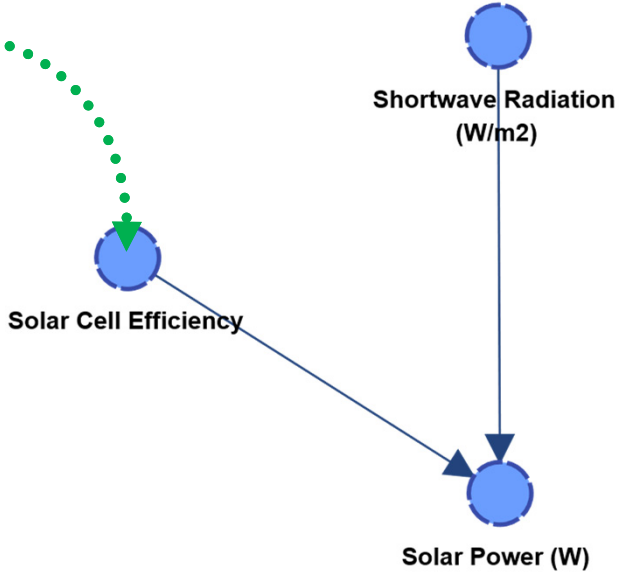


# Best Research-Cell Efficiencies




Best Research-Cell Efficiencies
NREL
Transforming ENERGY
Cell Efficiency (%)
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Emerging PV
Dye-sensitized cells
Perovskite cells
Perovskite/Si tandem (monolithic)
Organic cells (various types)
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells (various types)
Perovskite/CIGS tandem (monolithic)
47.1%
44.4%
39.2%
37.9%
35.5%
32.9%
30.5%
29.1%
27.6%
26.7%
26.1%
25.2%
24.2%
23.4%
23.3%
22.1%
21.2%
17.4%
16.6%
14.2%
14.0%
12.4%
12.3%
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020

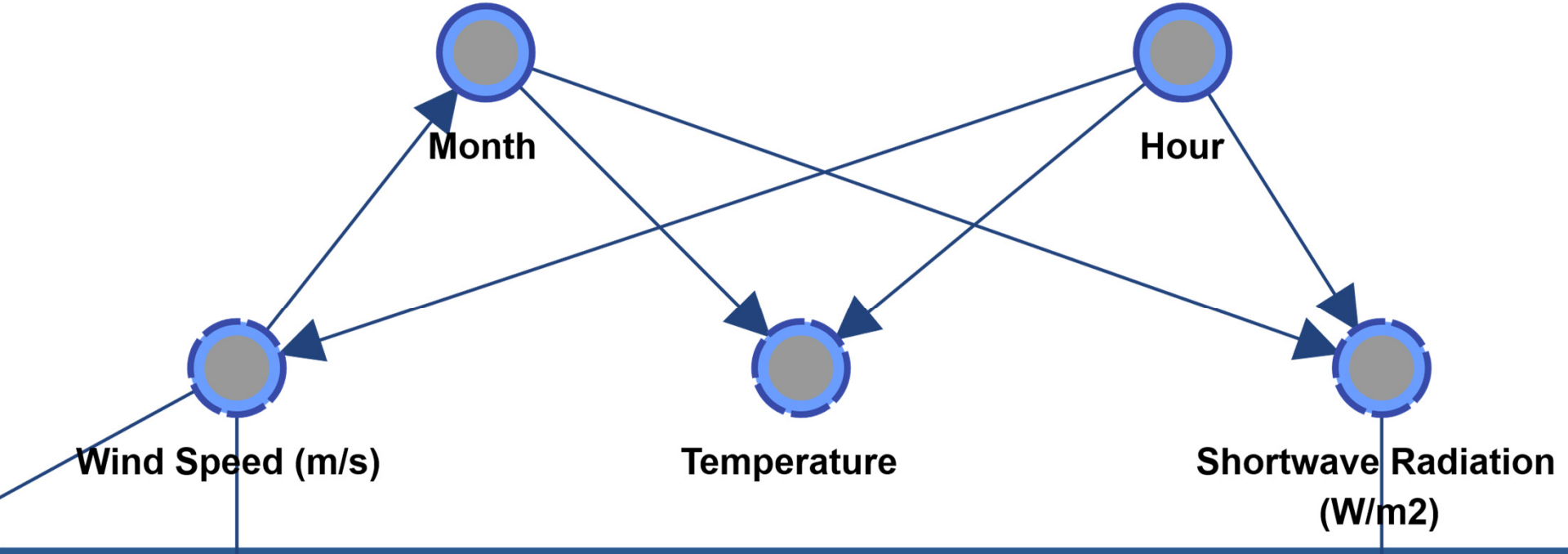

Shortwave Radiation (W/m2)
Solar Cell Efficiency
Solar Power (W)

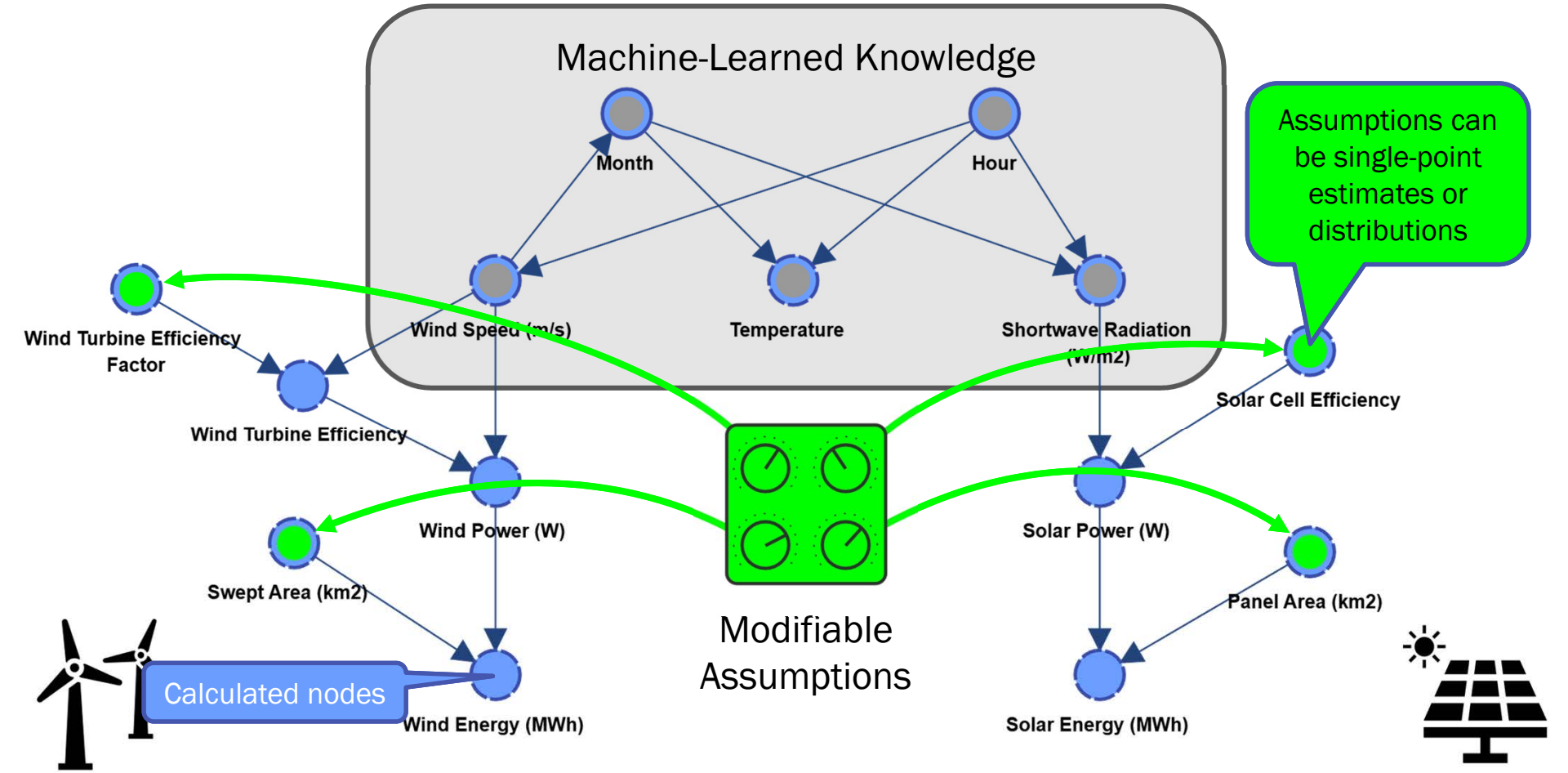
# Domain Knowledge

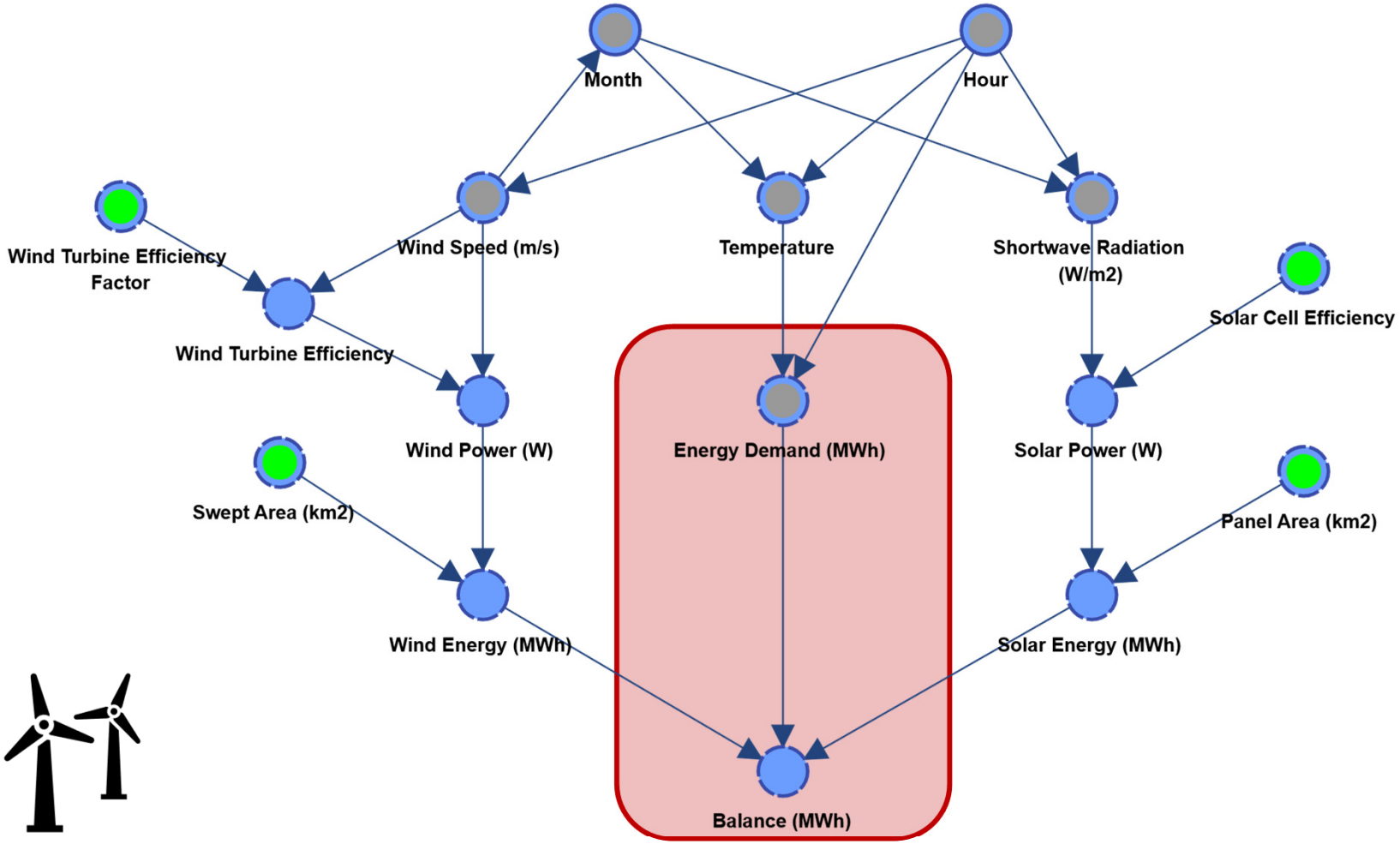
## Modeling Assumptions

- Surface area of solar panels and swept area of wind turbines are infinitely scalable.
- Solar panel efficiency is constant.
- Wind turbine efficiency is wind speed-dependent.
- Gas turbine efficiency is load dependent.

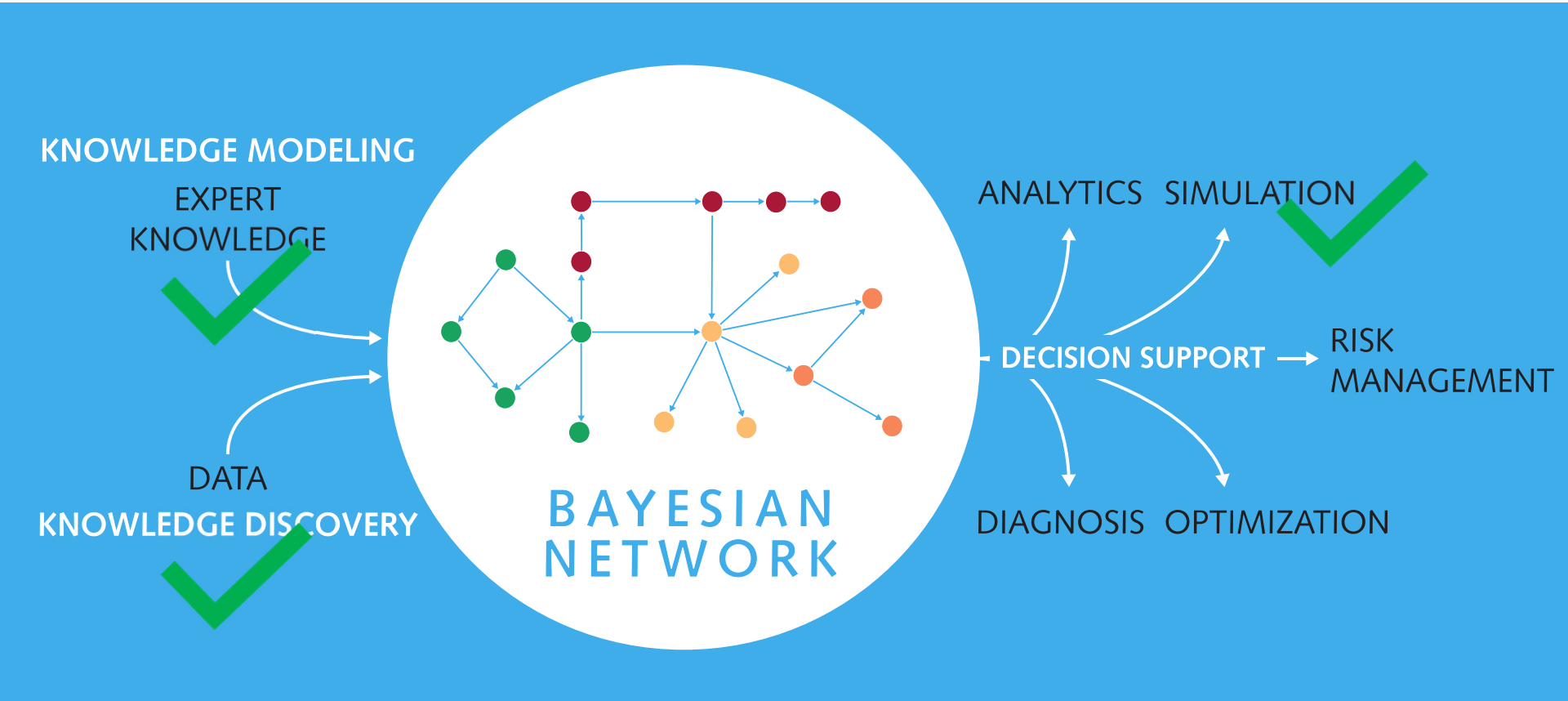
# Machine-Learned Knowledge

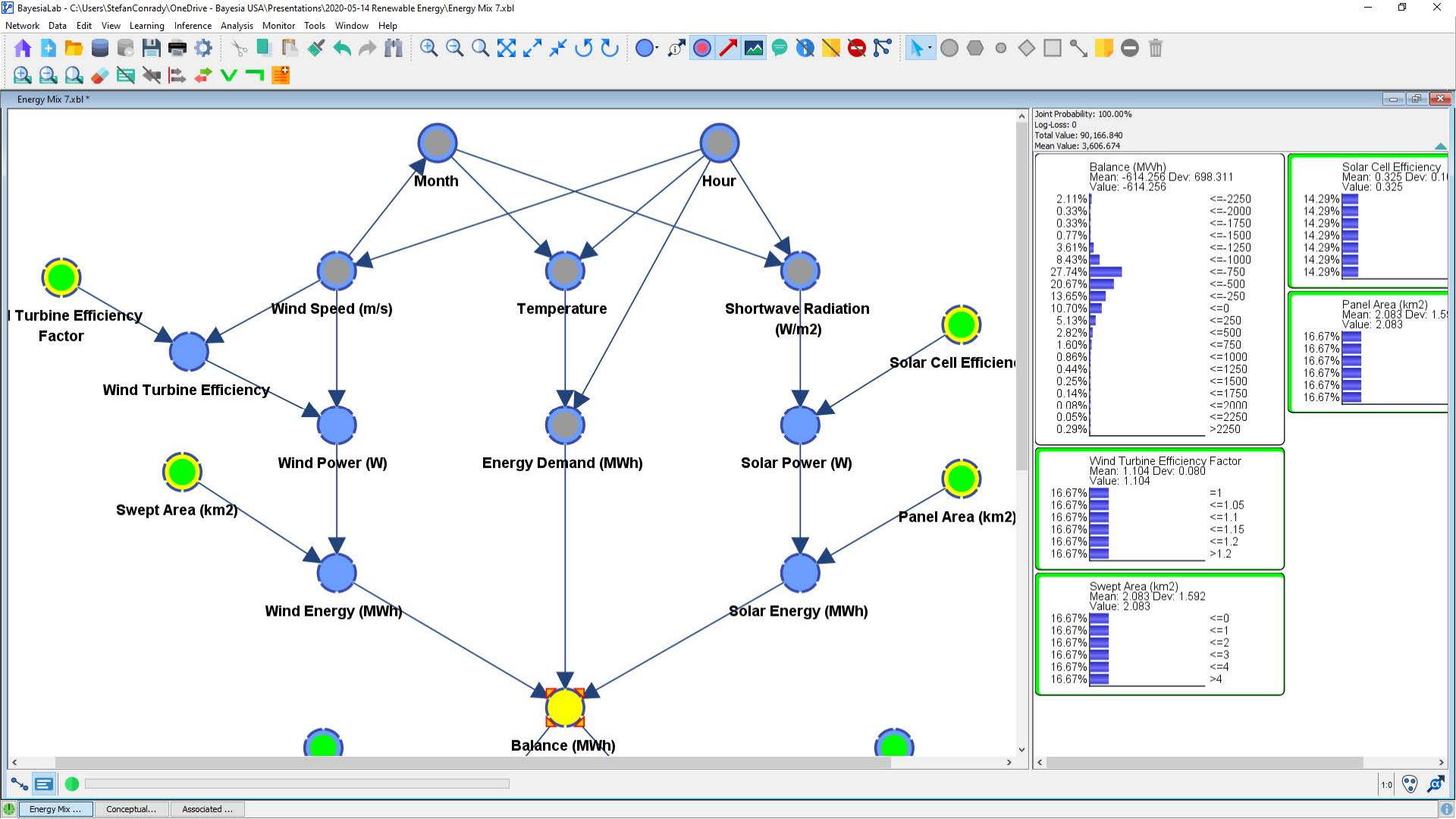



Machine-Learned Knowledge
Month
Hour
Temperature
Shortwave Radiation (W/m2)
Wind Speed (m/s)
Wind Turbine Efficiency Factor
Wind Turbine Efficiency
Wind Power (W)
Swept Area (km2)
Wind Energy (MWh)
Solar Cell Efficiency
Solar Power (W)
Panel Area (km2)
Solar Energy (MWh)
Assumptions can be single-point estimates or distributions
Modifiable Assumptions
Calculated nodes


Month
Hour
Wind Turbine Efficiency Factor
Wind Speed (m/s)
Temperature
Shortwave Radiation (W/m2)
Solar Cell Efficiency
Wind Turbine Efficiency
Wind Power (W)
Energy Demand (MWh)
Solar Power (W)
Swept Area (km2)
Panel Area (km2)
Wind Energy (MWh)
Solar Energy (MWh)
Balance (MWh)

# Reasoning Framework: Bayesian Networks




BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Presentations\2020-05-14 Renewable Energy\Energy Mix 7.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Energy Mix 7.xbl *
Month
Hour
Wind Speed (m/s)
Temperature
Shortwave Radiation (W/m2)
Turbine Efficiency Factor
Wind Turbine Efficiency
Solar Cell Efficien
Wind Power (W)
Energy Demand (MWh)
Solar Power (W)
Swept Area (km2)
Panel Area (km2)
Wind Energy (MWh)
Solar Energy (MWh)
Balance (MWh)
Joint Probability: 100.00%
Log-Loss: 0
Total Value: 90,166.840
Mean Value: 3,606.674
Balance (MWh)
Mean: -614.256 Dev: 698.311
Value: -614.256
2.11% <=-2250
0.33% <=-2000
0.33% <=-1750
0.77% <=-1500
3.61% <=-1250
8.43% <=-1000
27.74% <=-750
20.67% <=-500
13.65% <=-250
10.70% <=0
5.13% <=250
2.82% <=500
1.60% <=750
0.86% <=1000
0.44% <=1250
0.25% <=1500
0.14% <=1750
0.08% <=2000
0.05% <=2250
0.29% >2250
Solar Cell Efficiency
Mean: 0.325 Dev: 0.1
Value: 0.325
14.29%
Panel Area (km2)
Mean: 2.083 Dev: 1.5
Value: 2.083
16.67%
Wind Turbine Efficiency Factor
Mean: 1.104 Dev: 0.080
Value: 1.104
16.67% =1
16.67% <=1.05
16.67% <=1.1
16.67% <=1.15
16.67% <=1.2
16.67% >1.2
Swept Area (km2)
Mean: 2.083 Dev: 1.592
Value: 2.083
16.67% <=0
16.67% <=1
16.67% <=2
16.67% <=3
16.67% <=4
16.67% >4
Energy Mix ...
Conceptual...
Associated ...

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Network Data Edit View Learning Inference Analysis Monitor Tools Window Help

Visual
Report
Network Performance
Target Optimization
Function Optimization

Overall
Target
Segment
Graph
Sensitivity
Most Probable Explanation

Target's Posterior
Interpretation Tree
Mutual Information
Contributions

Histograms Shift+I
Tornado Diagrams
Curves

Total Effects V
Direct Effects

Energy Mix 7.xbl *

Joint Probability: 100.00%
Log-Loss: 0
Total Value: 90,166.840
Mean Value: 3,606.674

Month
Wind Speed (m/s)
Temperature
Turbine Efficiency Factor
Wind Turbine Efficiency
Wind Power (W)
Energy Demand (MWh)
Swept Area (km2)
Wind Energy (MWh)
Balance (MWh)

Target Mean Analysis by Direct Effects

Node:
x:
y:

Balance (MWh) Mean

-400
-450
-500
-550
-600
-650
-700
-750
-800

0 10 20 30 40 50 60 70 80 90 100

Normalized Variable Means

Variables

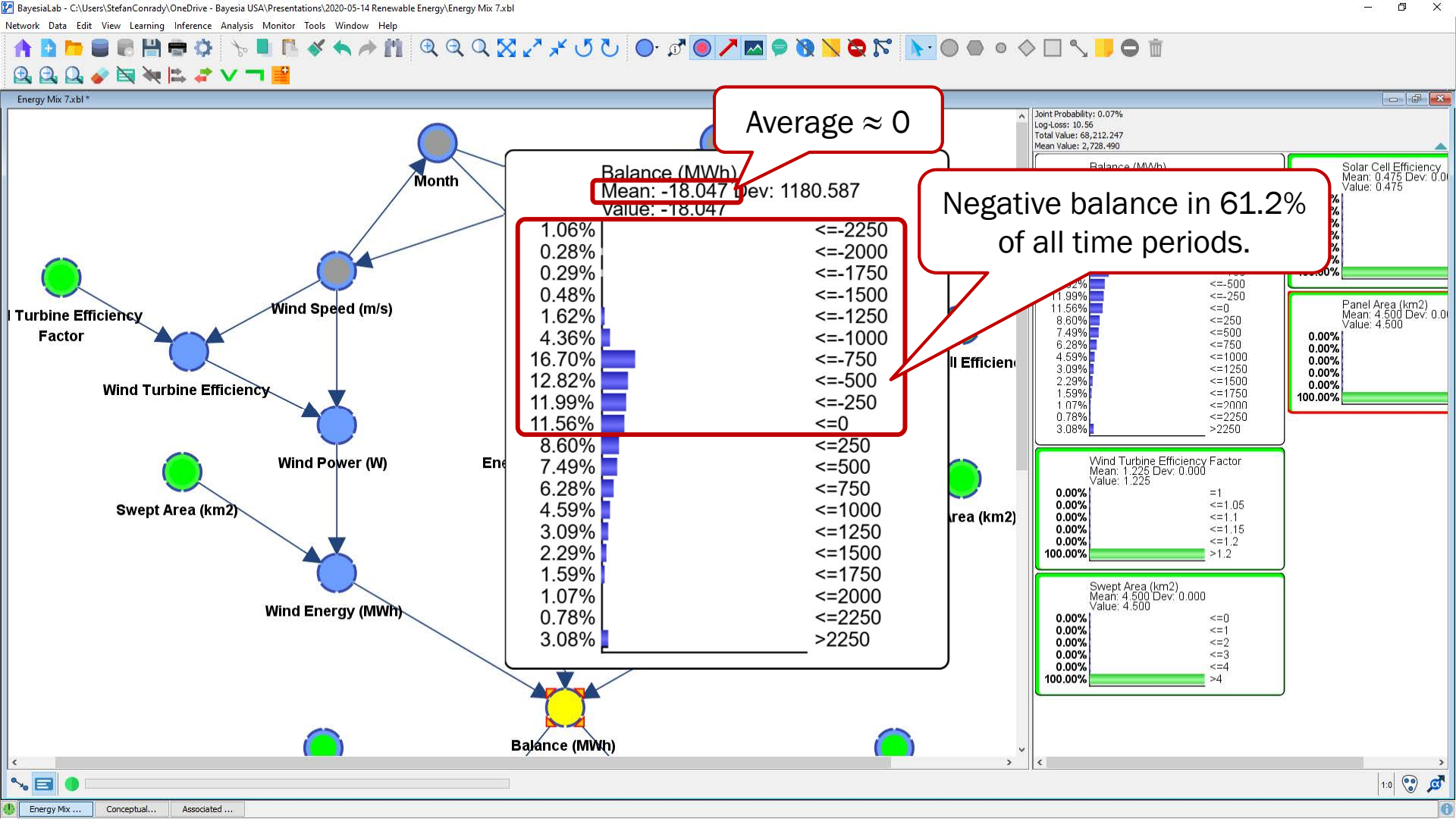
All Curves
Panel Area (km2)
Swept Area (km2)
Solar Cell Efficiency
Wind Turbine Efficiency Factor

Close Save

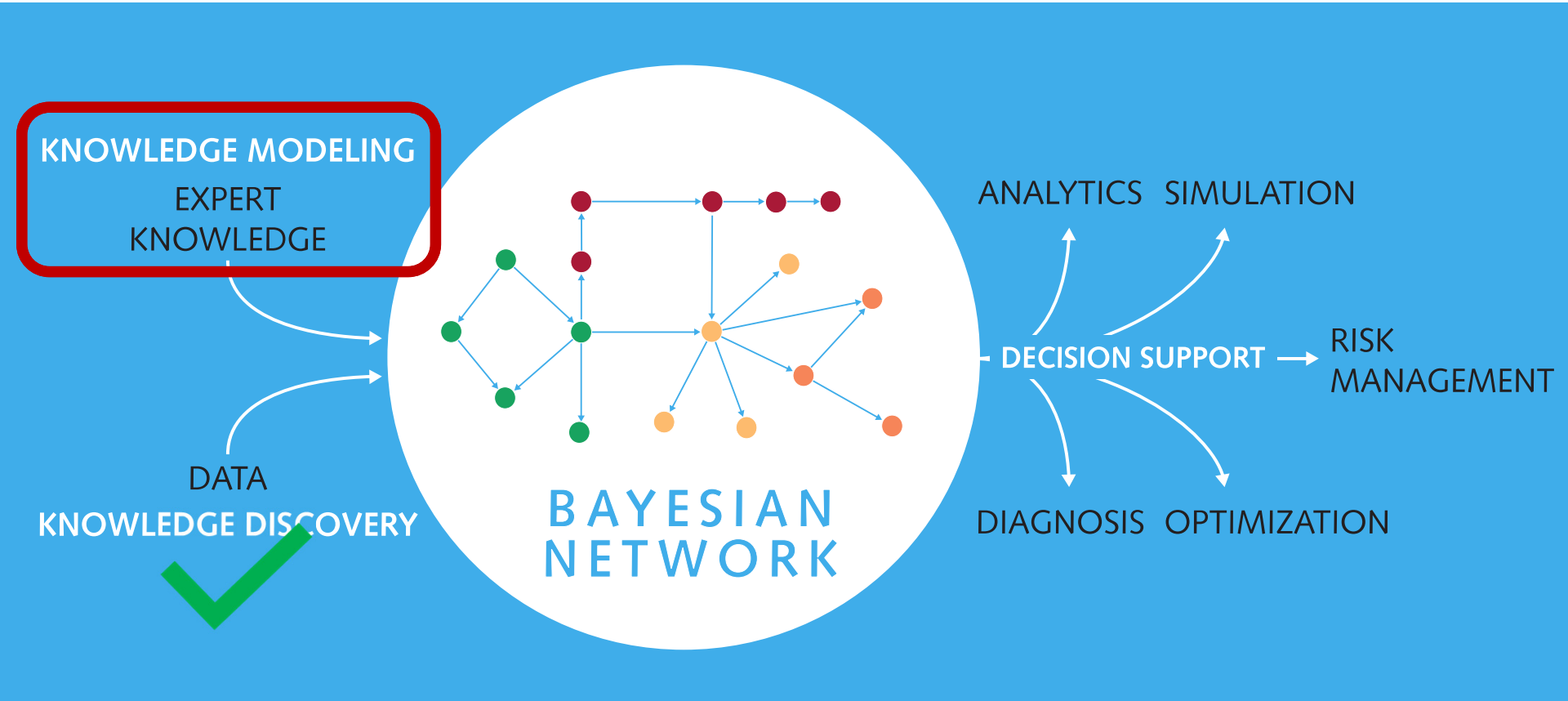
Efficiency
25 Dev: 0.1
25

a (km2)
83 Dev: 1.5
83

Energy Mix ... Conceptual... Associated ...


BayesiaLab - C:\Users\StefanConrady\OneDrive - Bayesia USA\Presentations\2020-05-14 Renewable Energy\Energy Mix 7.xbl
Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Energy Mix 7.xbl *
Average ≈ 0
Negative balance in 61.2% of all time periods.
Balance (MWh)
Mean: -18.047 Dev: 1180.587
Value: -18.047
1.06% <=-2250
0.28% <=-2000
0.29% <=-1750
0.48% <=-1500
1.62% <=-1250
4.36% <=-1000
16.70% <=-750
12.82% <=-500
11.99% <=-250
11.56% <=0
8.60% <=250
7.49% <=500
6.28% <=750
4.59% <=1000
3.09% <=1250
2.29% <=1500
1.59% <=1750
1.07% <=2000
0.78% <=2250
3.08% >2250
Month
Wind Speed (m/s)
Wind Turbine Efficiency
Wind Power (W)
Swept Area (km2)
Wind Energy (MWh)
Balance (MWh)
Joint Probability: 0.07%
Log-Loss: 10.56
Total Value: 68,212.247
Mean Value: 2,728.490
Solar Cell Efficiency
Mean: 0.475 Dev: 0.0
Value: 0.475
Panel Area (km2)
Mean: 4.500 Dev: 0.0
Value: 4.500
0.00%
0.00%
0.00%
0.00%
0.00%
100.00%
Wind Turbine Efficiency Factor
Mean: 1.225 Dev: 0.000
Value: 1.225
0.00% =1
0.00% <=1.05
0.00% <=1.1
0.00% <=1.15
0.00% <=1.2
100.00% >1.2
Swept Area (km2)
Mean: 4.500 Dev: 0.000
Value: 4.500
0.00% <=0
0.00% <=1
0.00% <=2
0.00% <=3
0.00% <=4
100.00% >4
Energy Mix ...
Conceptual...
Associated ...

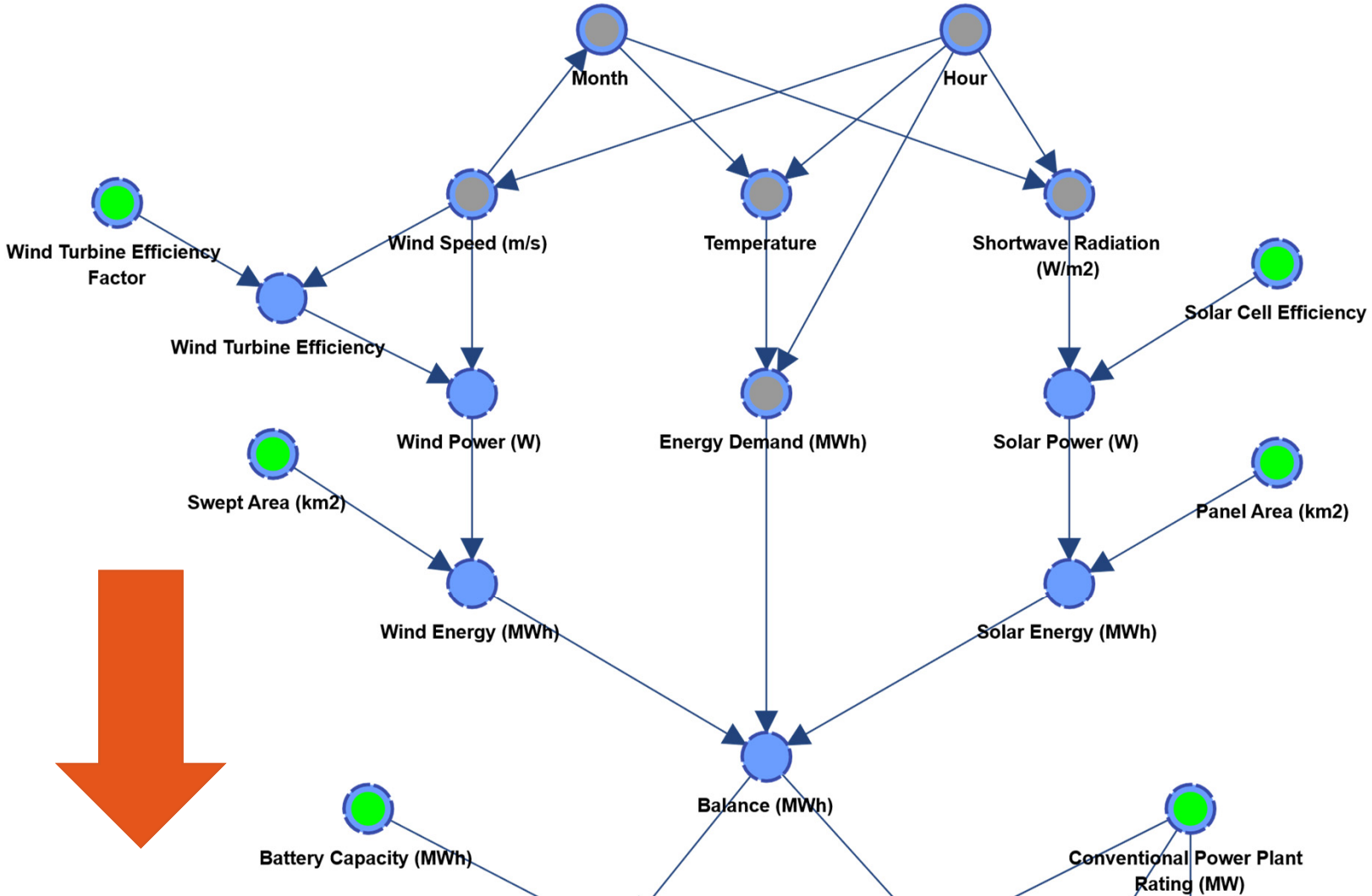
# Reasoning Framework: Bayesian Networks

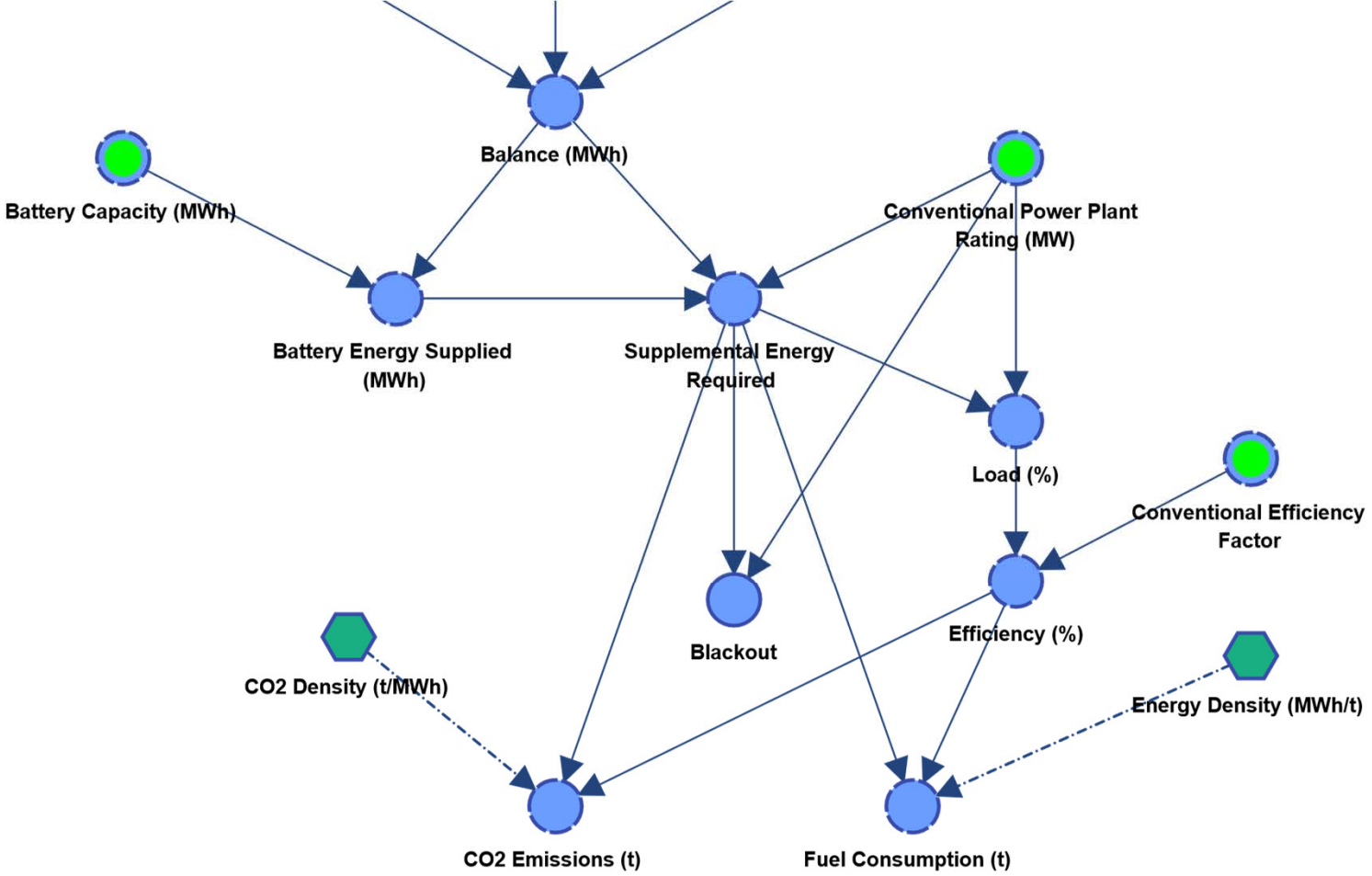


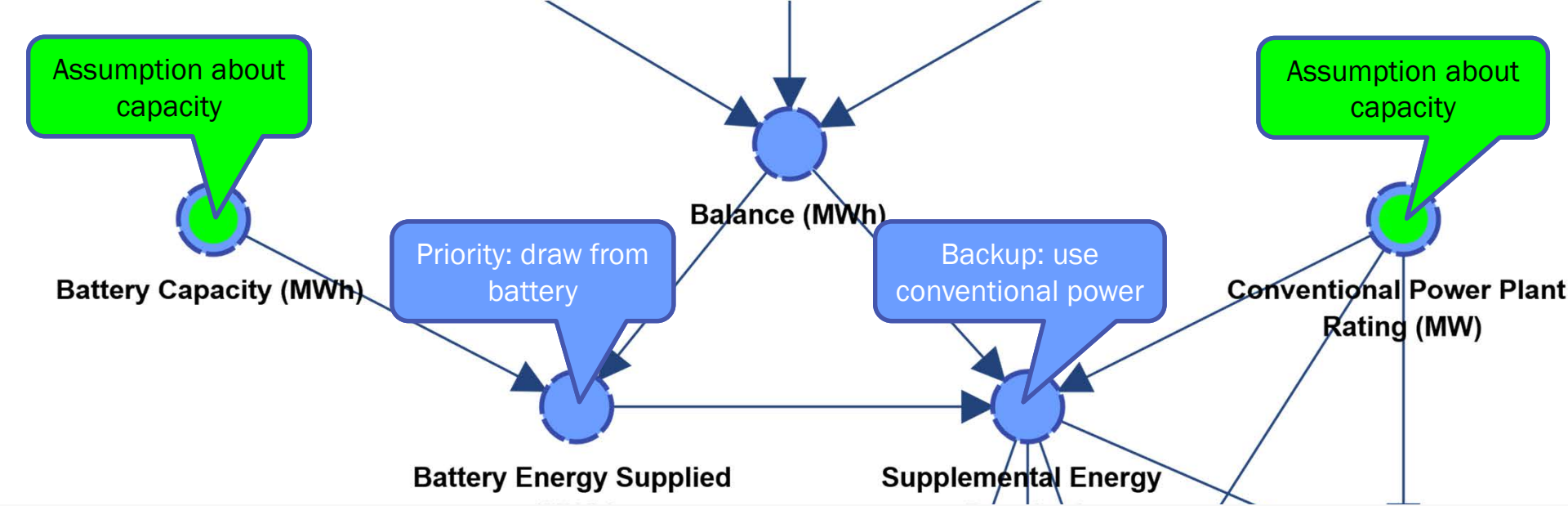
# Battery Storage

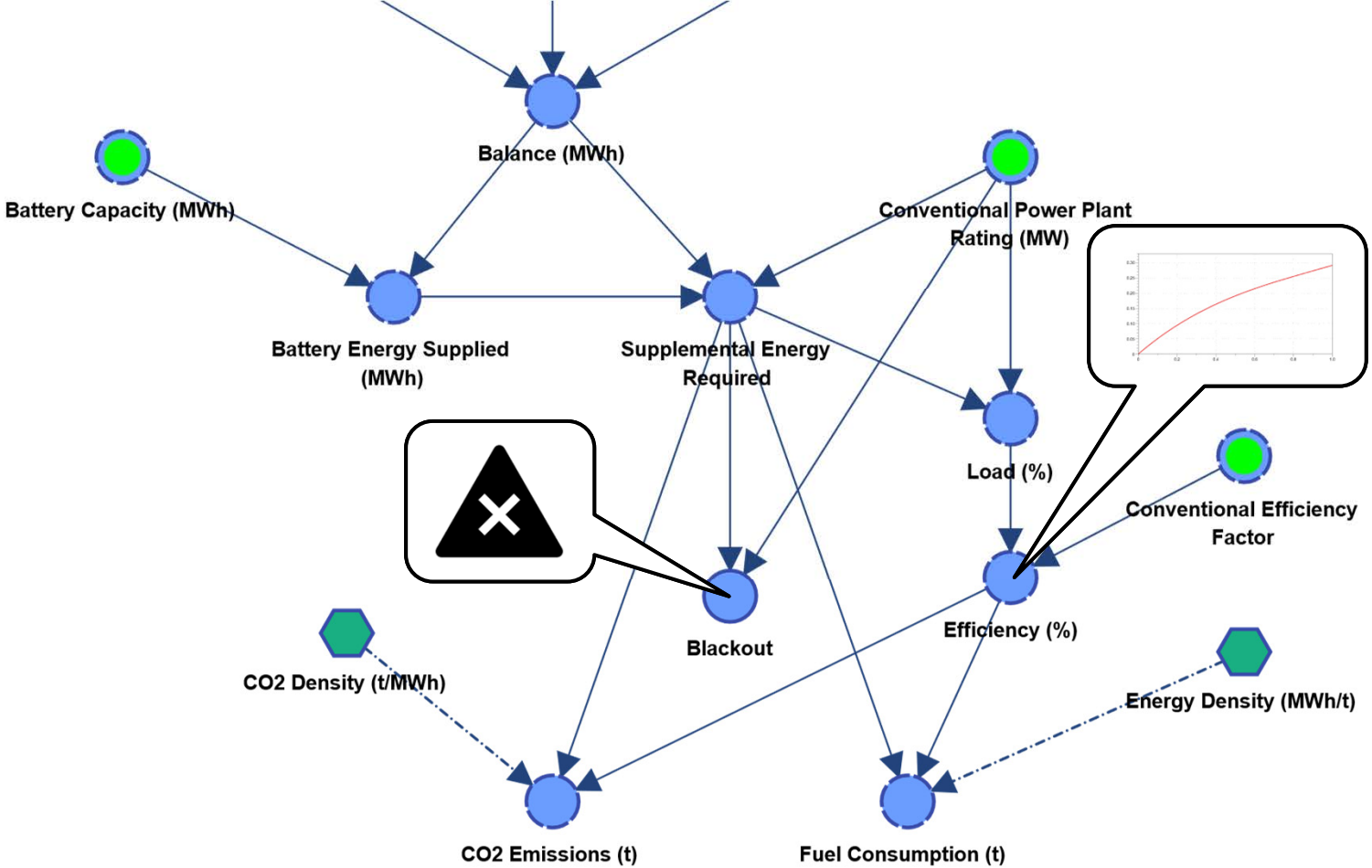
# Caveat

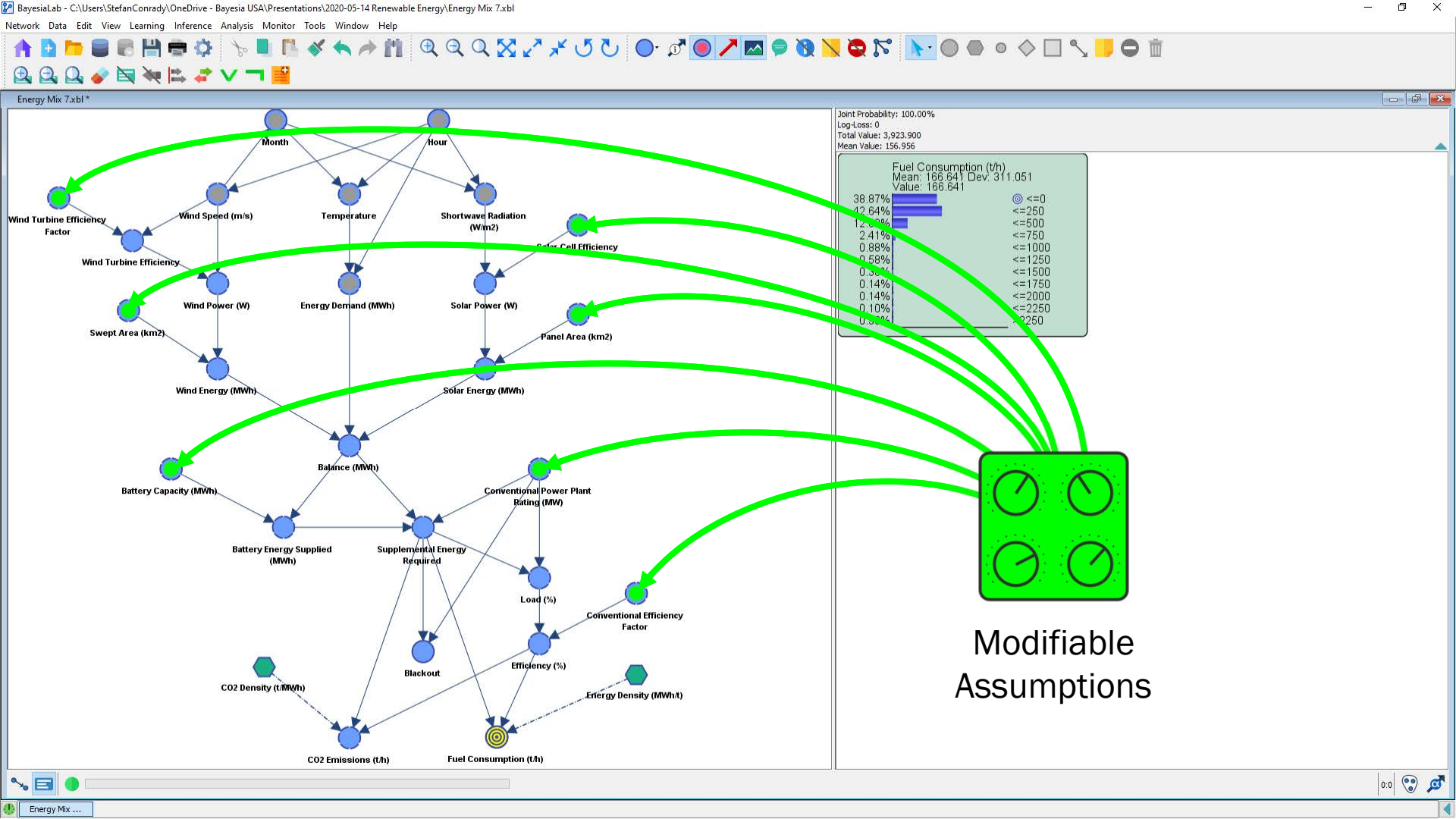
# Conventional Power Plant


Month
Hour
Wind Turbine Efficiency Factor
Wind Speed (m/s)
Temperature
Shortwave Radiation (W/m2)
Solar Cell Efficiency
Wind Turbine Efficiency
Wind Power (W)
Energy Demand (MWh)
Solar Power (W)
Swept Area (km2)
Panel Area (km2)
Wind Energy (MWh)
Solar Energy (MWh)
Balance (MWh)
Battery Capacity (MWh)
Conventional Power Plant Rating (MW)


Balance (MWh)
Battery Capacity (MWh)
Conventional Power Plant Rating (MW)
Battery Energy Supplied (MWh)
Supplemental Energy Required
Load (%)
Conventional Efficiency Factor
Blackout
Efficiency (%)
CO2 Density (t/MWh)
Energy Density (MWh/t)
CO2 Emissions (t)
Fuel Consumption (t)


Assumption about capacity
Assumption about capacity
Balance (MWh)
Battery Capacity (MWh)
Priority: draw from battery
Backup: use conventional power
Conventional Power Plant Rating (MW)
Battery Energy Supplied
Supplemental Energy


Balance (MWh)
Battery Capacity (MWh)
Conventional Power Plant Rating (MW)
Battery Energy Supplied (MWh)
Supplemental Energy Required
Load (%)
Conventional Efficiency Factor
Blackout
Efficiency (%)
CO2 Density (t/MWh)
Energy Density (MWh/t)
CO2 Emissions (t)
Fuel Consumption (t)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Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Energy Mix 7.xbl *
Month
Hour
Wind Turbine Efficiency Factor
Wind Speed (m/s)
Temperature
Shortwave Radiation (W/m2)
Solar Cell Efficiency
Wind Turbine Efficiency
Wind Power (W)
Energy Demand (MWh)
Solar Power (W)
Swept Area (km2)
Panel Area (km2)
Wind Energy (MWh)
Solar Energy (MWh)
Balance (MWh)
Battery Capacity (MWh)
Conventional Power Plant Rating (MW)
Battery Energy Supplied (MWh)
Supplemental Energy Required
Load (%)
Conventional Efficiency Factor
Blackout
Efficiency (%)
CO2 Density (t/MWh)
Energy Density (MWh/t)
CO2 Emissions (t/h)
Fuel Consumption (t/h)
Joint Probability: 100.00%
Log-Loss: 0
Total Value: 3,923.900
Mean Value: 156.956
Fuel Consumption (t/h)
Mean: 166.641 Dev: 311.051
Value: 166.641
38.87% <=0
42.64% <=250
12.[illegible]% <=500
2.41% <=750
0.88% <=1000
0.58% <=1250
0.[illegible]% <=1500
0.14% <=1750
0.14% <=2000
0.10% <=2250
0.[illegible]% >2250
Modifiable Assumptions
Energy Mix ...

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Visual
Report
Network Performance
Target Optimization
Function Optimization

Overall
Target
Segment
Graph
Sensitivity
Most Probable Explanation

Target's Posterior
Interpretation Tree
Mutual Information
Contributions

Histograms Shift+I
Tornado Diagrams
Curves

Total Effects V
Direct Effects

Energy Mix 7.xbl

Wind Turbine Efficiency Factor
Wind Speed (m/s)
Temperature
Shortwave Radiation (W/m2)
Solar Cell Efficiency
Wind Turbine Efficiency
Wind Power (W)
Energy Demand (MWh)
Solar Power (W)
Swept Area (km2)
Panel Area (km2)
Wind Energy (MWh)
Solar Energy (MWh)
Balance (MWh)
Battery Capacity (MWh)
Conventional Power Plant Rating (MW)
Battery Energy Supplied (MWh)
Supplemental Energy Required
Load (%)
Conventional Efficiency Factor
Blackout
Efficiency (%)
CO2 Density (t/MWh)
Energy Density (MWh/t)
CO2 Emissions (t/h)
Fuel Consumption (t/h)

Target Mean Analysis by Direct Effects

Node:
x:
y:

Fuel Consumption (t/h) Mean

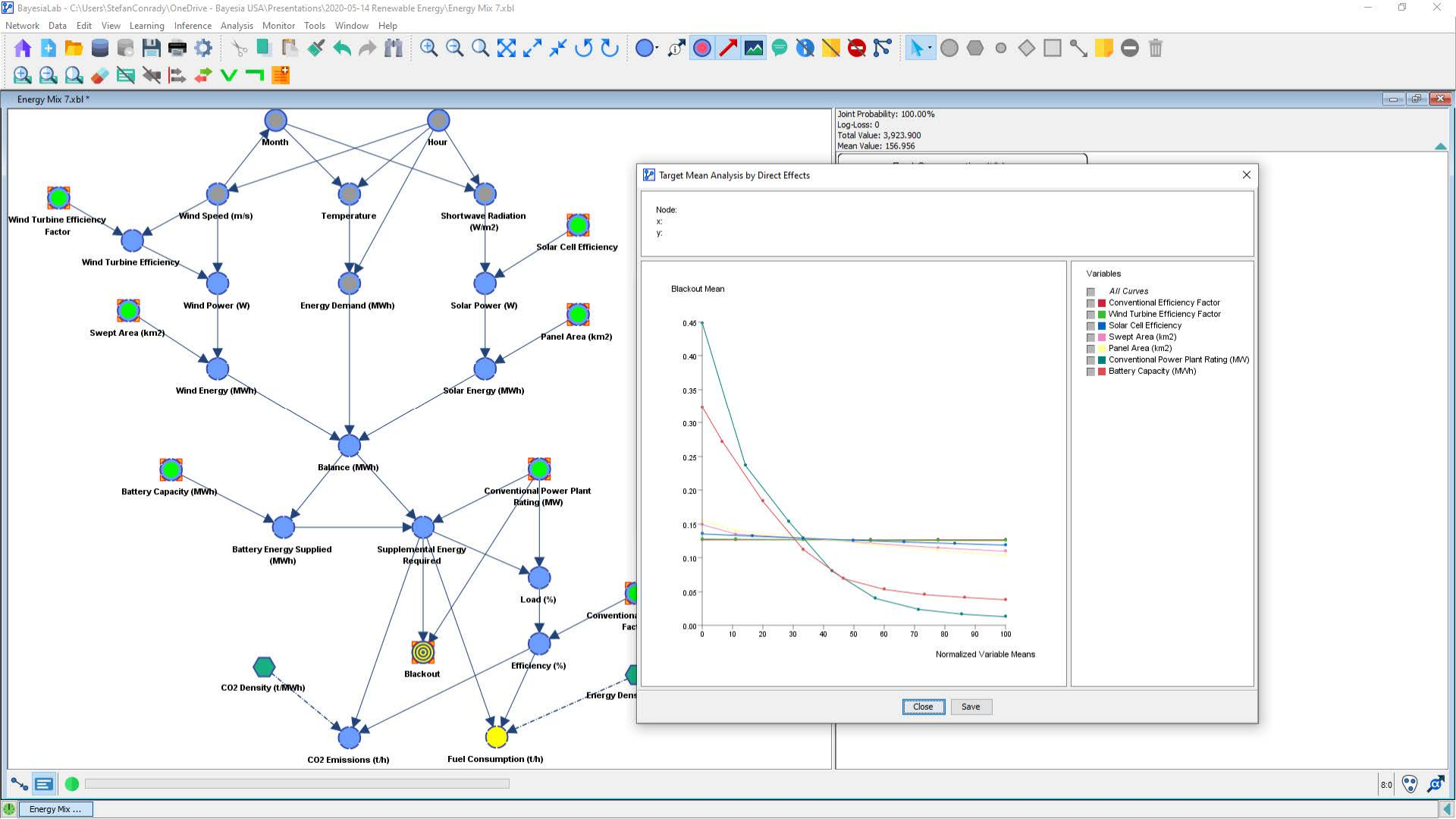
260
240
220
200
180
160
140
120
100
0 10 20 30 40 50 60 70 80 90 100

Normalized Variable Means

Variables
All Curves
Conventional Power Plant Rating (MW)
Wind Turbine Efficiency Factor
Solar Cell Efficiency
Conventional Efficiency Factor
Panel Area (km2)
Swept Area (km2)
Battery Capacity (MWh)

Close Save

Energy Mix ...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Network Data Edit View Learning Inference Analysis Monitor Tools Window Help
Energy Mix 7.xbl *
Joint Probability: 100.00%
Log-Loss: 0
Total Value: 3,923.900
Mean Value: 156.956
Month
Hour
Wind Turbine Efficiency Factor
Wind Speed (m/s)
Temperature
Shortwave Radiation (W/m2)
Solar Cell Efficiency
Wind Turbine Efficiency
Wind Power (W)
Energy Demand (MWh)
Solar Power (W)
Swept Area (km2)
Panel Area (km2)
Wind Energy (MWh)
Solar Energy (MWh)
Balance (MWh)
Battery Capacity (MWh)
Conventional Power Plant Rating (MW)
Battery Energy Supplied (MWh)
Supplemental Energy Required
Load (%)
Blackout
Efficiency (%)
CO2 Density (t/MWh)
CO2 Emissions (t/h)
Fuel Consumption (t/h)
Target Mean Analysis by Direct Effects
Node:
x:
y:
Blackout Mean
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0 10 20 30 40 50 60 70 80 90 100
Normalized Variable Means
Variables
All Curves
Conventional Efficiency Factor
Wind Turbine Efficiency Factor
Solar Cell Efficiency
Swept Area (km2)
Panel Area (km2)
Conventional Power Plant Rating (MW)
Battery Capacity (MWh)
Close
Save
Energy Mix ...

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Network Data Edit View Learning Inference Analysis Monitor Tools Window Help

Visual
Report
Network Performance
Target Optimization
Function Optimization

Overall
Target
Segment
Graph
Sensitivity
Most Probable Explanation

Target's Posterior
Interpretation Tree
Mutual Information
Contributions

Histograms Shift+I
Tornado Diagrams
Curves

Total Effects
Direct Effects

Energy Mix 7.xbl *

Wind Turbine Efficiency Factor
Wind Speed (m/s)
Temperature
Shortwave Radiation (W/m2)
Solar Cell Efficiency
Wind Turbine Efficiency
Wind Power (W)
Energy Demand (MWh)
Solar Power (W)
Swept Area (km2)
Panel Area (km2)
Wind Energy (MWh)
Solar Energy (MWh)
Balance (MWh)
Battery Capacity (MWh)
Conventional Power Plant Rating (MW)
Battery Energy Supplied (MWh)
Supplemental Energy Required
Load (%)
Conventional Efficiency Factor
Blackout
Efficiency (%)
CO2 Density (t/MWh)
Energy Density (MWh/t)
CO2 Emissions (t/h)
Fuel Consumption (t/h)

Probability: 100.00%
Log-Loss: 0
Total Value: 3,923.900
Mean Value: 156.956

Fuel Consumption (t/h)

Posterior Probability Analysis of Blackout (Energy Mix 7)

Blackout False True Mean

Blackout

Conventional Power Plant Rating (MW)
Battery Capacity (MWh)
Panel Area (km2)
Swept Area (km2)
Solar Cell Efficiency
Wind Turbine Efficiency Factor
Conventional Efficiency Factor

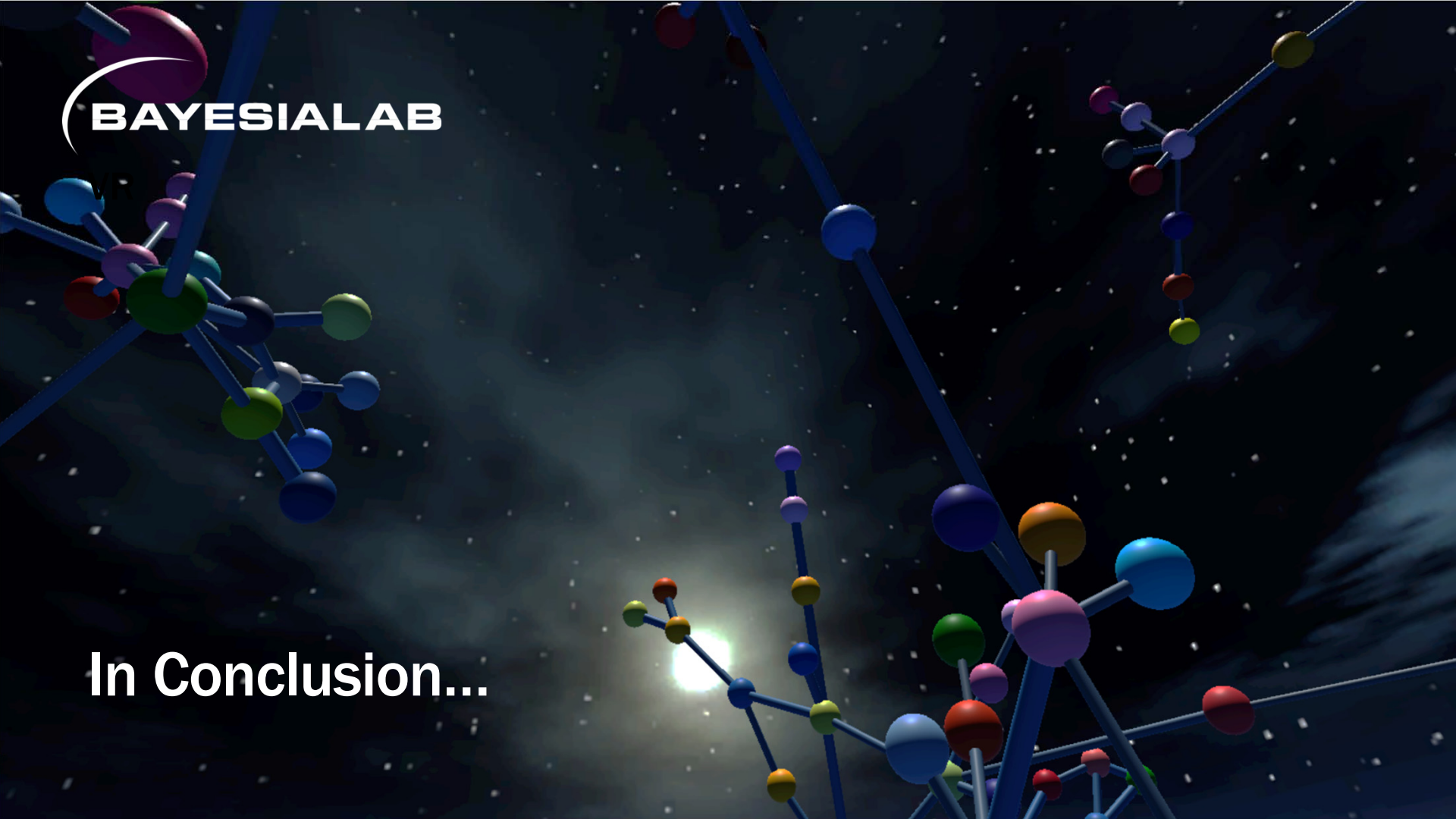
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45

Mean of Blackout

Blackout
Mean (0.1264)

Close

Energy Mix ...


BAYESIALAB
In Conclusion...

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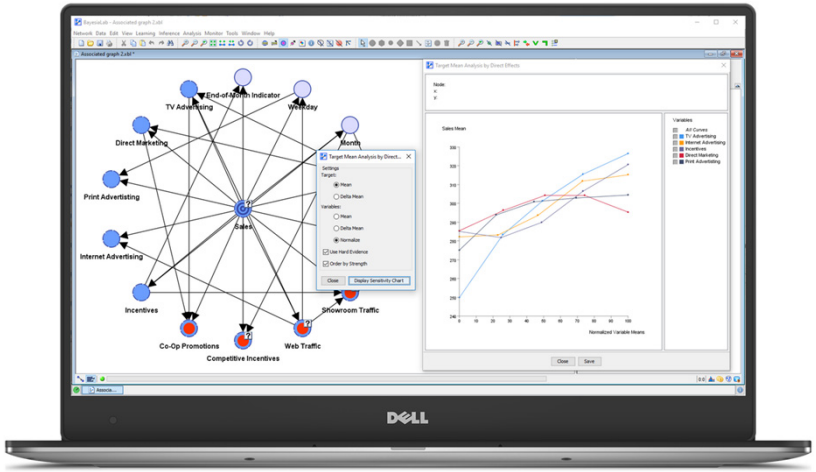

# Webinar Series

## Reasoning Under Uncertainty

- March 20 Part 1 — Differential Diagnosis of Diseases
- March 26 Part 2 — Pandemic Triage with Bayesian Networks
- April 9 Part 3 — Epidemic Modeling with Temporal Bayesian Networks
- April 30 Part 4 — Representing Spatial and Temporal Dynamics
- May 14 Part 5 — Reasoning About Renewable Energy
- May 28 t.b.d.

**Program Subject to Change — Check for Updates**

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# Thank you!


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