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Integrated Energy Systems

FORCE Training: Tool for Economic AnaLysis (TEAL)

Integrated Energy Systems (IES) Tools: Capability Overview and Training

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Elizabeth K. Worsham, Ph.D.

Summary

- What is TEAL?
- Financial Basics
- Components and Cash Flows
- Example: Nuclear Plant
- Example: Power Plant Optimization

What is TEAL

- Tool for Economic AnaLysis, or TEAL, is a RAVEN plugin that calculates characteristics of cash flows.
- TEAL is a useful behind-the-scenes part of HERON, but it can also be helpful as an independent tool.
- Calculations are based on components and cash flows associated with each component.
- TEAL can be used for static calculations and parametric studies of cases that are not time-dependent.

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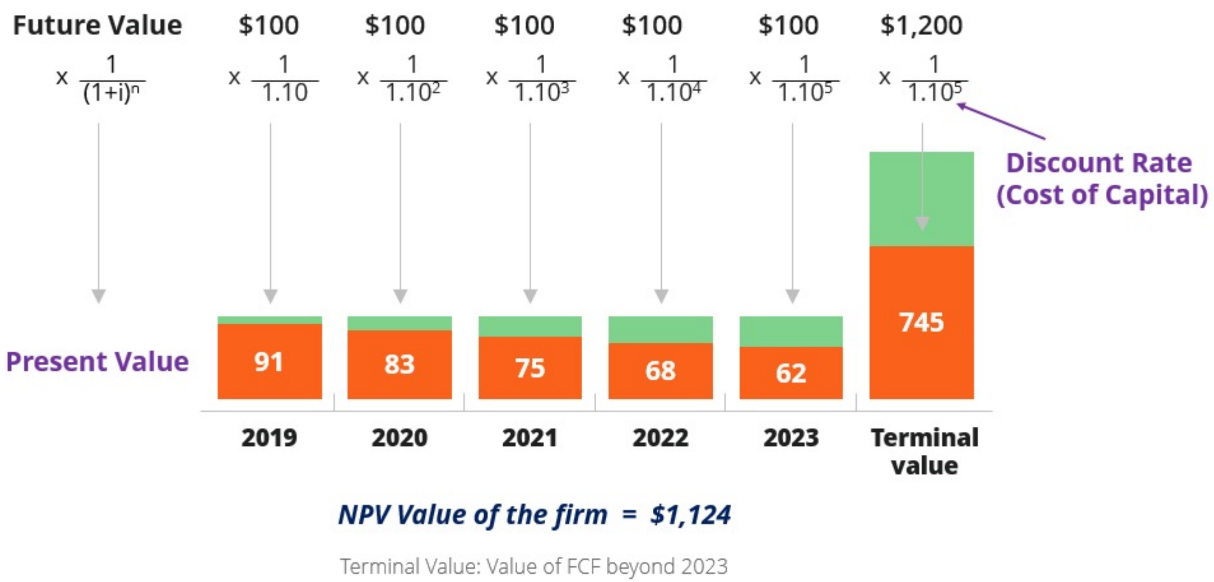
Net Present Value

- The Net Present Value (NPV) is the present year value of a future cash flow based on a discount (or interest) rate.
- Used to determine the long-term value of an investment



https://corporatefinanceinstitute.com/course/corporate-finance-fundamentals/

$$NPV = \sum_{y=0}^{N} \frac{CF_y}{(1+WACC)^y}$$

NPV > 0	NPV = 0	NPV < 0
Investment has a positive return	Breakeven	Investment has a negative return

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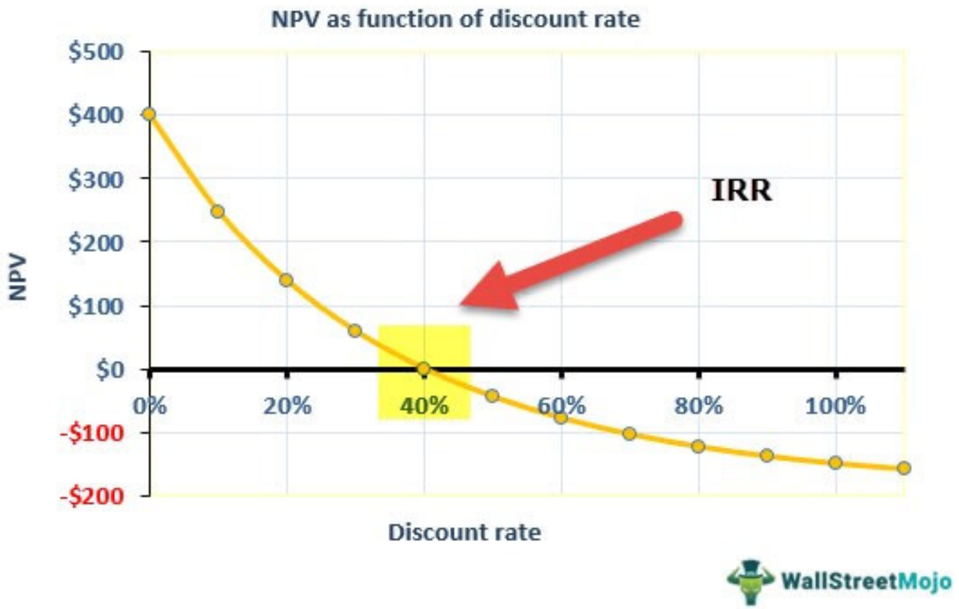
Internal Rate of Return

- The internal rate of return (IRR) is the discount rate at which the NPV = 0.
- Most useful for comparison of prospective investment options – A higher IRR means a higher expected growth rate.

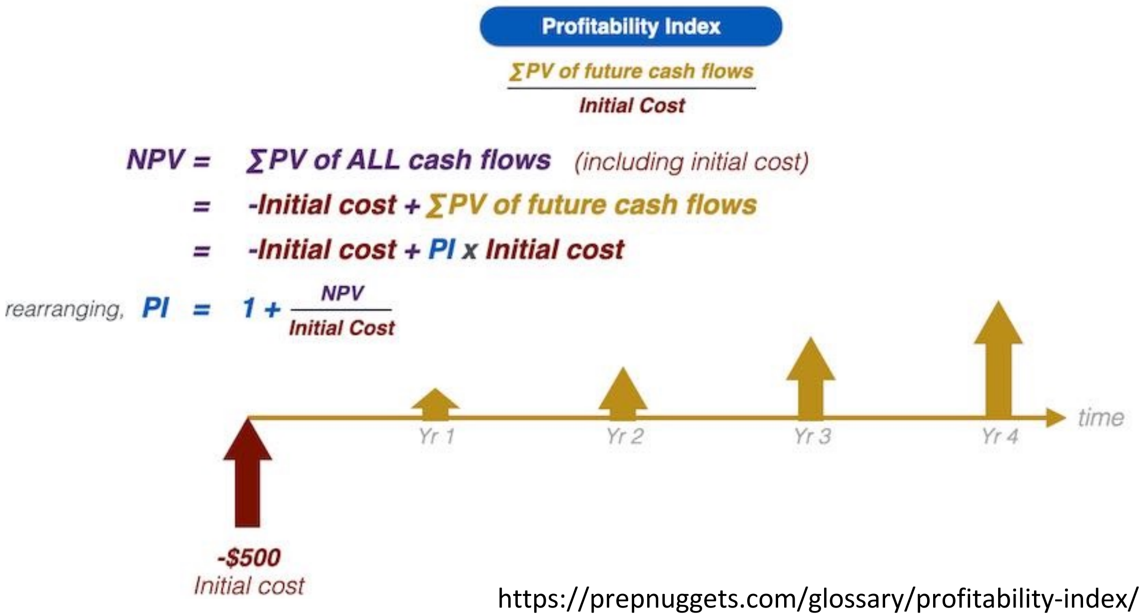


https://www.wallstreetmojo.com/internal-rate-of-return-irr/

$$0 = \sum_{y=0}^{N} \frac{CF_y}{(1+IRR)^y}$$

Profitability Index

- Profitability Index (PI) is the ratio of a projects future cash flows to the initial investment.
- PI cannot be negative – a PI < 1.0 means the NPV of future cash flows are less than the initial investment and a PI > 1.0 means they are more.



https://prepnuggets.com/glossary/profitability-index/

$$PI = \frac{NPV}{Initial\_investment}$$

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NPV Search

- Finds a multiplier “x” which multiplies some cash flows to obtain the “target” NPV.
  - To do an IRR search, set the discount rate to the desired IRR and perform an NPV search with a target of 0
  - To do a PI search, perform an NPV search where the target PI is multiplied with the initial investment.

$$'target' = \sum_{y=0}^{N} \frac{CF_y^{dep\_on\_x}}{(1+DiscountRate)^y} x + \sum_{y=0}^{N} \frac{CF_y^{not\_dep\_on\_x}}{(1+DiscountRate)^y}$$

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Global Variables

- Contains attributes that will be applied to all components and cash flows
- Specify ALL cash flows in the indicator block. Only the cash flows listed here will be applied by RAVEN.

```
<Global>
    <Indicator name='IRR,NPV_search,NPV' target='0'>
        Component1|Cfname1
        Component1|Cfname2
        ...
    </Indicator>
    <DiscountRate>0.08</DiscountRate>
    <tax>0.392</tax>
    <inflation>0.04</inflation>
    <ProjectTime>100</ProjectTime> <!-- optional -->
</Global>
```

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Component Definition

- Cash Flows are contained within “components.” A component can be a material component (like a power plant or turbine) or a non-material component (like an electric market).
- You can have unlimited components and unlimited cash flows
- NPV, PI and IRR will be computed for the least common multiple of all component lifetimes UNLESS a project length is specified.
  - Components will be rebuilt at the end of their lifetime.
  - Component 1 has a life of 10 years, and component 2 has a life of 25 years. Component 1 is rebuilt 4 times and Component 2 is rebuilt once for a LCM of 50 years.
  - If the project length is 25 years, Component 1 will be rebuilt once and component 2 will not be rebuilt
  - You can also specify a start time and number of rebuilds/repetitions.
- You can specify a specific tax or inflation rate here

```
<Component name='Component1'>
    <Life_time>20</Life_time>
    <StartTime>10</StartTime> <!-- optional -->
    <Repetitions>3</Repetitions> <!-- optional -->
    <tax>0.3</tax> <!-- optional -->
    <inflation>0.07</inflation> <!-- optional -->
```

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Cash Flow Definition

- Two kinds of cash flows
  - Capex: Applied only when the component is built – capital expenditure
  - Recurring: Applied at every time step (typically a year)

```
<Capex name='Cfname1' tax='false' inflation='none'
   multiply='multiplier1' mult_target='false'>
    <driver>Cfdriver1</driver>
    <alpha>-4000000000</alpha>
    <reference>1000000000</reference>
    <X>1.0</X>
</Capex>

<Recurring name='Cfname2' tax='false'
   inflation='none' multiply='multiplier2'
   mult_target='true'>
    ...
</Recurring>
```

$$CF_y = mult \cdot \alpha_y \left(\frac{driver_y}{ref} \right)^X$$

The variable “driving” the cash flow

Optional multiplier

Scaling factor

A multiplier related to the reference value (e.g. the cost of a 1 MW turbine)

A reference value relating to the driver (e.g. a 1 MW turbine)

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RAVEN Basics

- See the user manual for more info

```
<VariableGroups>
    <Group name="GRO_CashFlow_in">Cfdriver1,
      Cfdriver2</Group>
    <Group name="GRO_CashFlow_out">NPV</Group>
</VariableGroups>

<!-- Required for using TEAL with RAVEN -->
<Models>
    <ExternalModel name="Cash_Flow" subType="TEAL.CashFlow">
        <variables>GRO_CashFlow_in,
          GRO_CashFlow_out</variables>
        <ExternalXML node="Economics"
          xmlToLoad="Cash_Flow_input.xml"/>
    </ExternalModel>
</Models>
```

List ALL drivers

Specify TEAL as an external model

```
<Samplers>
    <MonteCarlo name="MC">
        <samplerInit>
            <limit>100</limit>
        </samplerInit>
        <variable name="Cfdriver1">
            <function>driver_1</function>
        </variable>
        <constant name="Cfdriver2">10000</constant>
    </MonteCarlo>
</Samplers>
```

Custom function

Fixed

Example: Nuclear Plant

- You want to build a nuclear power plant at 500 MW capacity. The cost of a 1 GW plant is $1 billion with a scaling factor of 0.75. The yearly O+M Cost of the plant is $20/MWh with $1,000/MW fixed costs. The plant is expected to run at 97% capacity for 60 years with an average yearly electricity price of $35/MWh. The discount rate is 5%.

TEAL
(Cashflow Calculations)

	Nuclear Plant	Electric Grid
Component	Nuclear Plant	Electric Grid
CashFlow	CapEx	Recurring (Demand)
Driver	Plant_Capacity	Load_Hours
Reference	1 GW	
Alpha	-$1 billion	+$35/Mwh
Scaling Factor	0.75	
CashFlow	Recurring (Fixed)	
Driver	Plant_Capacity	
Alpha	-$1,000/MW	
CashFlow	Recurring (Variable)	
Driver	Load_Hours	
Alpha	-$20/MWh	

Don't forget to normalize units!

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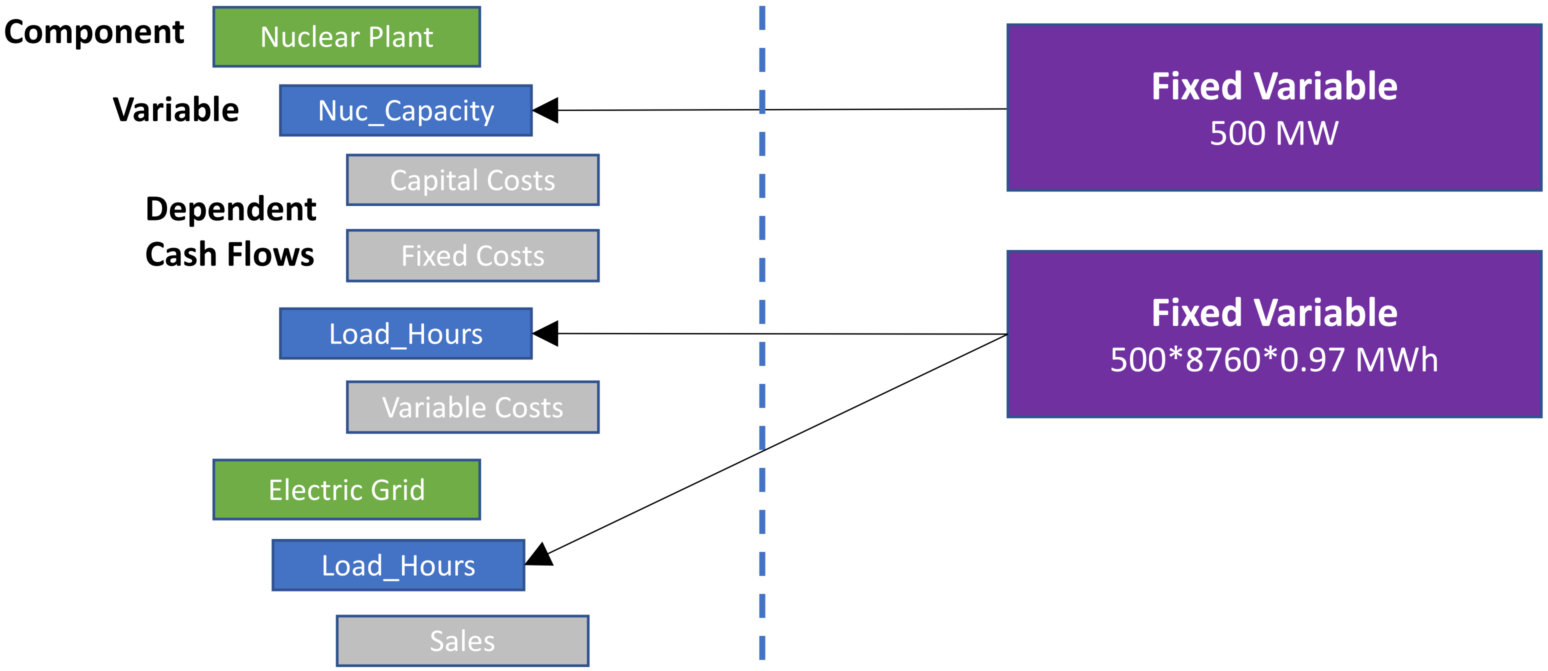
TEAL Interacting with RAVEN

TEAL
(Cashflow Calculations)

RAVEN
(Functions and Sampling)



Plant_capacity	500
Load_hours	4,248,600
NPV	$ 602,276,490
IRR	0.106
PI	1.013

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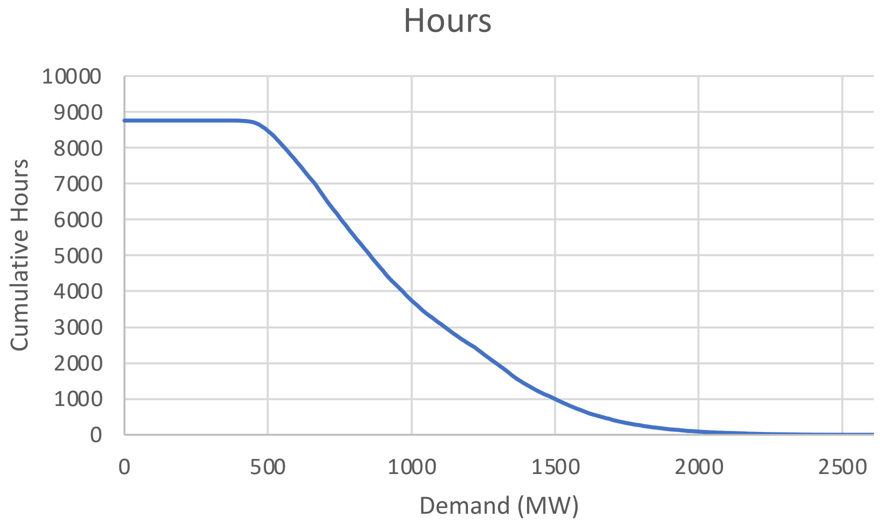
Example: Coal and Nuclear Plant Optimization

- Optimize a combination of a nuclear power plant and coal power plant with CCS in a region with the specified load curve. The average electricity price every year is $35/MWh. The system must meet the maximum demand of 2610 MW.



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Example: Coal and Nuclear Plant Optimization

Component Coal Plant

CashFlow CapEx

Driver C_Capacity

Reference 1 MW

Alpha -$3,000,000

Scaling Factor 1

Recurring (Fixed)

Driver C_Capacity

Alpha -$1,000/MW

Recurring (Variable)

Driver Op_hours

Alpha -$50/MWh

Component Nuclear Plant

CashFlow CapEx

Driver N_Capacity

Reference 1 MW

Alpha -$2,000,000

Scaling Factor 1

Recurring (Fixed)

Driver N_Capacity

Alpha -$233,016/MW

The nuclear plant is considered to have only fixed costs -- $28/MWh * 8760 hr/yr * 95% capacity

Electric Grid

Recurring (Sales)

Driver Demand

Alpha +$35/Mwh

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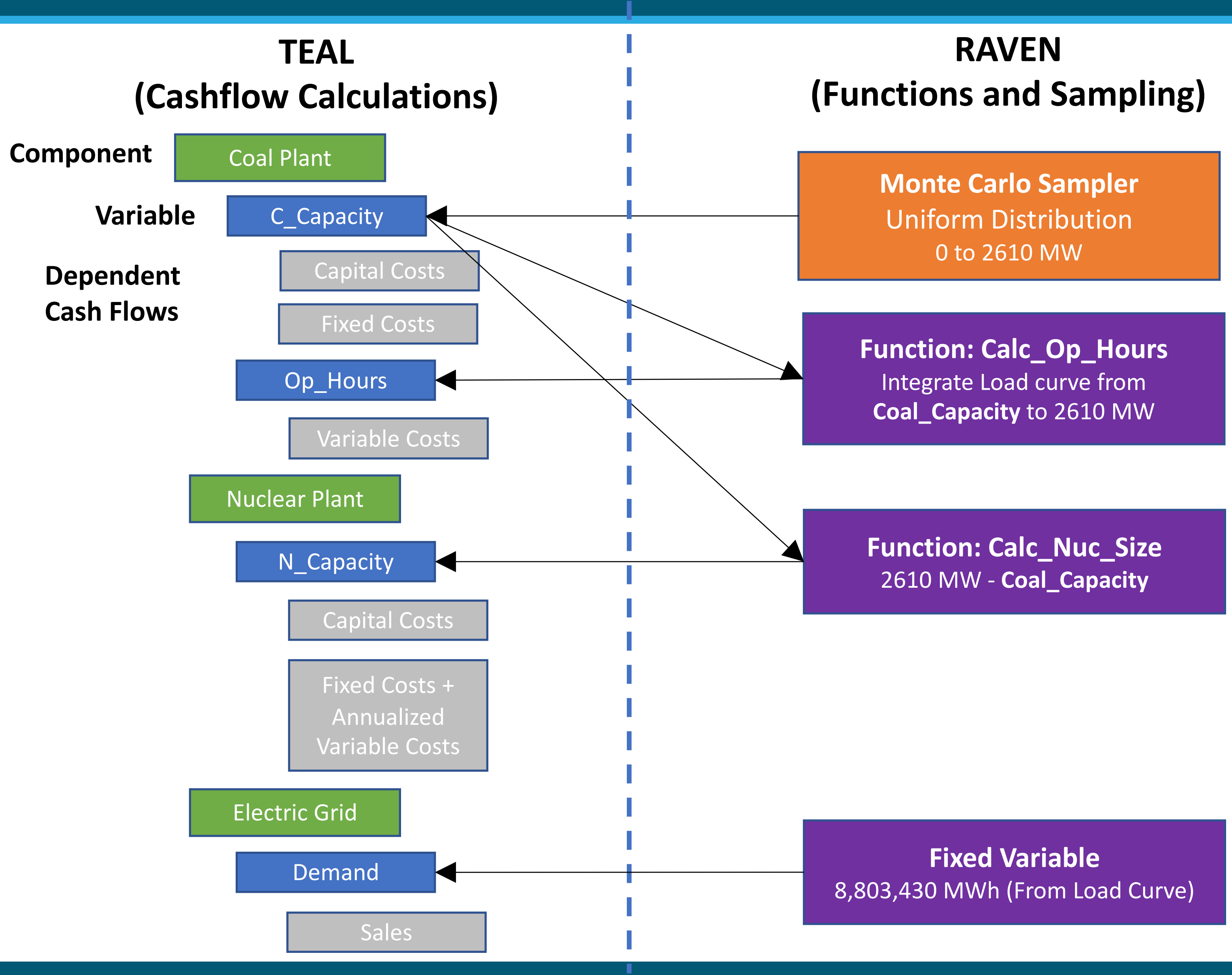
Interacting With RAVEN



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Custom Functions

- Custom functions are vital for variable studies on components that interact with each other.
  - Pull variables from RAVEN into a Python Function
  - More details in the RAVEN manual

Python Function

```python
import numpy as np
def evaluate(self):
    NCap = self.MaxCapacity - self.Coal_capacity
    return NCap
```

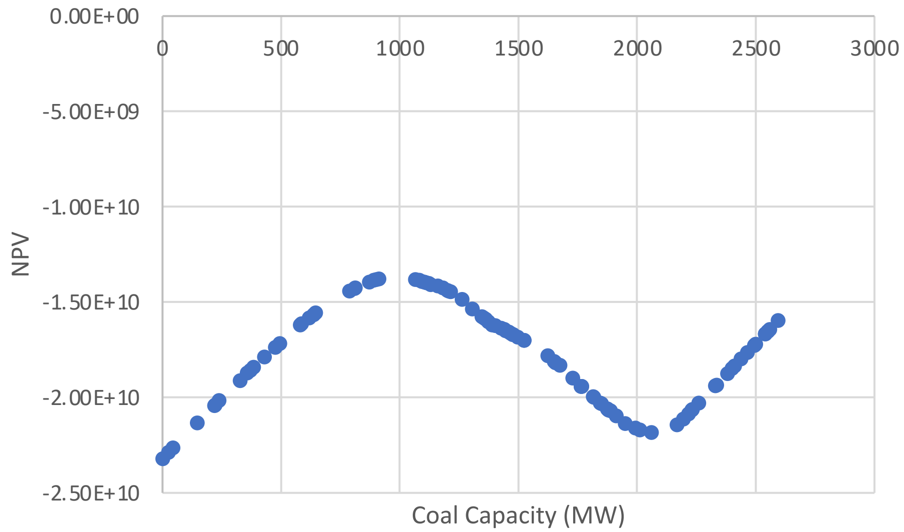
RAVEN Input

```xml
<Functions>
    <External name="NCapacity" file="NCapacity.py">
        <variables>MaxCapacity, Coal_capacity</variables>
    </External>

    <External name="CoalDemand" file="CoalDemandImport.py">
        <variables>AR_capacity,MaxCapacity</variables>
    </External>
</Functions>
```

Results

- The optimal design is around 1000 MW for the coal plant
- You can add secondary markets or different generators to improve the outcome



Top 5 Optimal Designs

N_capacity	C_capacity	Demand	MaxCapacity	Op_Hours	NPV
1698	912	8803430	2610	793404	-1.38E+10
1546	1064	8803430	2610	1447391	-1.4E+10
1709	901	8803430	2610	751204	-1.38E+10
1721	889	8803430	2610	713567	-1.39E+10
1528	1082	8803430	2610	1544663	-1.39E+10

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TEAL is an underrated tool!

- Requires only basic knowledge of RAVEN
- Great for single calculations or non-time-dependent analysis
- Intuitive use of custom functions
- Easy parametric studies

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