example

March 20, 2020

1 Tyche Example

1.1 Set up.

1.1.1 One only needs to execute the following line once, in order to make sure recent enough packages are installed.

[ ]:
```
!pip install 'numpy>=1.17.2' 'pandas>=0.25.1'
```

1.1.2 Import packages.

[1]:
```
import numpy             as np
import matplotlib.pyplot as pl
import pandas            as pd
import re                as re

# The `tyche` package is located at <https://github.com/NREL/portfolio/tree/
↪master/production-function/framework/code/tyche/>.
import tyche             as ty
```

1.2 Load data.

1.2.1 The data are stored in a set of tab-separated value files in a folder.

[2]:
```
scenarios = ty.Designs("../data")
```

1.2.2 Compile the production and metric functions for each technology in the dataset.

[3]:
```
scenarios.compile()
```

1.3 Examine the data.

1.3.1 The `functions` table specifies where the Python code for each technology resides.

[4]:
```
scenarios.functions
```

[4]:
```
                                     Module  Production  Metrics Notes
Technology
Simple electrolysis  simple_electrolysis  production  metrics
```

1.3.2 The `indices` table defines the subscripts for variables.

[5]:
```
scenarios.indices
```

[5]:
```
                                            Offset  Description Notes
Technology          Type    Index
Simple electrolysis Capital Catalyst             0     Catalyst
                    Fixed   Rent                 0         Rent
                    Input   Electricity          1  Electricity
                            Water                0        Water
                    Metric  Jobs                 0         Jobs
                    Output  Hydrogen             1     Hydrogen
                            Oxygen               0       Oxygen
```

1.3.3 The `designs` table contains the cost, input, efficiency, and price data for a scenario.

[6]:
```
scenarios.designs
```

[6]:
```
                                                                      Value  \
Technology          Scenario    Variable          Index
Simple electrolysis Alternative Capital cost      Catalyst         0.630000
                                Fixed cost        Rent          1000.000000
                                Input             Electricity    279.000000
                                                  Water           19.040000
                                Input efficiency  Electricity      0.875000
                                                  Water            0.975000
                                Input price       Electricity      0.000033
                                                  Water            0.004800
                                Lifetime          Catalyst         3.000000
                                Output efficiency Hydrogen         0.950000
                                                  Oxygen           0.950000
                                Output price      Hydrogen         0.010000
                                                  Oxygen           0.003000
                                Scale             NaN           6650.000000
                    Base        Capital cost      Catalyst         0.630000
                                Fixed cost        Rent          1000.000000
                                Input             Electricity    279.000000
                                                  Water           19.040000
```

```
                                         Input efficiency  Electricity     0.850000
                                                           Water           0.950000
                                         Input price       Electricity     0.000033
                                                           Water           0.004800
                                         Lifetime          Catalyst        3.000000
                                         Output efficiency Hydrogen        0.900000
                                                           Oxygen          0.900000
                                         Output price      Hydrogen        0.010000
                                                           Oxygen          0.003000
                                         Scale             NaN          6650.000000

                                                                           Units  \
Technology          Scenario    Variable          Index
Simple electrolysis Alternative Capital cost      Catalyst                   USD
                                Fixed cost        Rent                    USD/yr
                                Input             Electricity            kJ/mole
                                                  Water                   g/mole
                                Input efficiency  Electricity                  1
                                                  Water                        1
                                Input price       Electricity             USD/kJ
                                                  Water                 USD/mole
                                Lifetime          Catalyst                    yr
                                Output efficiency Hydrogen                     1
                                                  Oxygen                       1
                                Output price      Hydrogen                 USD/g
                                                  Oxygen                   USD/g
                                Scale             NaN                    mole/yr
                    Base        Capital cost      Catalyst                   USD
                                Fixed cost        Rent                    USD/yr
                                Input             Electricity            kJ/mole
                                                  Water                   g/mole
                                Input efficiency  Electricity                  1
                                                  Water                        1
                                Input price       Electricity             USD/kJ
                                                  Water                 USD/mole
                                Lifetime          Catalyst                    yr
                                Output efficiency Hydrogen                     1
                                                  Oxygen                       1
                                Output price      Hydrogen                 USD/g
                                                  Oxygen                   USD/g
                                Scale             NaN                    mole/yr

               Notes
Technology          Scenario    Variable          Index
Simple electrolysis Alternative Capital cost      Catalyst
Al-Ni catalyst.
                                Fixed cost        Rent
```

```
                                      Input             Electricity
                                                        Water
                                      Input efficiency  Electricity
                                                        Water
                                      Input price       Electricity
                                                        Water
                                      Lifetime          Catalyst     Effective
lifetime of Al-Ni catalyst.
                                      Output efficiency Hydrogen
                                                        Oxygen
                                      Output price      Hydrogen
                                                        Oxygen
                                      Scale             NaN                Rough
estimate for a 50W setup.
                    Base              Capital cost      Catalyst
Al-Ni catalyst.
                                      Fixed cost        Rent
                                      Input             Electricity
                                                        Water
                                      Input efficiency  Electricity
                                                        Water
                                      Input price       Electricity
                                                        Water
                                      Lifetime          Catalyst     Effective
lifetime of Al-Ni catalyst.
                                      Output efficiency Hydrogen
                                                        Oxygen
                                      Output price      Hydrogen
                                                        Oxygen
                                      Scale             NaN                Rough
estimate for a 50W setup.
```

1.3.4 The `parameters` table contains additional techno-economic parameters for each technology.

[7]:
```
scenarios.parameters
```

[7]:
```
                                                                 Offset       Value  \
Technology           Scenario    Parameter
Simple electrolysis Alternative Electricity consumption       3  237.00000
                                 Hydrogen production           1    2.00000
                                 Jobs                          4    0.00015
                                 Oxygen production             0   16.00000
                                 Water consumption             2   18.08000
                     Base        Electricity consumption       3  237.00000
                                 Hydrogen production           1    2.00000
                                 Jobs                          4    0.00015
```

```
                                          Oxygen production              0    16.00000
                                          Water consumption              2    18.08000

                                                                        Units Notes
Technology           Scenario    Parameter
Simple electrolysis Alternative Electricity consumption           kJ
                                 Hydrogen production                g
                                 Jobs                        job/mole
                                 Oxygen production                  g
                                 Water consumption                  g
                     Base        Electricity consumption           kJ
                                 Hydrogen production                g
                                 Jobs                        job/mole
                                 Oxygen production                  g
                                 Water consumption                  g
```

1.3.5 The `results` table specifies the units of measure for results of computations.

[8]:
```
scenarios.results
```

[8]:
```
                                                Units Notes
Technology           Variable Index
Simple electrolysis Cost     Cost         USD/mole
                     Metric   Jobs        jobs/mole
                     Output   Hydrogen       g/mole
                              Oxygen         g/mole
```

1.4 Evaluate the designs in the dataset.

[9]:
```
results = scenarios.evaluate_all()
```

[10]:
```
results
```

[10]:
```
                                                            Value      Units
Technology           Scenario    Variable Index
Simple electrolysis Alternative Cost     Cost        0.181315   USD/mole
                                 Metric   Jobs        0.000150  jobs/mole
                                 Output   Hydrogen    1.950863     g/mole
                                          Oxygen     15.606903     g/mole
                     Base        Cost     Cost        0.183900   USD/mole
                                 Metric   Jobs        0.000150  jobs/mole
                                 Output   Hydrogen    1.800796     g/mole
                                          Oxygen     14.406372     g/mole
```

1.5 Sensitity analysis.

1.5.1 Vary the four efficiencies in the design.

[11]:
```
# Four variables are involved.
variables = [
    ("Input efficiency" , "Water"       ),
    ("Input efficiency" , "Electricity"),
    ("Output efficiency", "Oxygen"      ),
    ("Output efficiency", "Hydrogen"    ),
]
```

[12]:
```
# Let efficiencies range from 0.75 to 0.975.
efficiencies = np.arange(0.750, 1.000, 0.025)
efficiencies
```

[12]:
```
array([0.75 , 0.775, 0.8  , 0.825, 0.85 , 0.875, 0.9  , 0.925, 0.95 ,
       0.975])
```

1.5.2 Start from the base case.

[13]:
```
base_design = scenarios.designs.xs("Base", level=1, drop_level=False)
base_design
```

[13]:
```
                                                                  Value  \
Technology           Scenario Variable          Index
Simple electrolysis Base     Capital cost      Catalyst        0.630000
                             Fixed cost        Rent         1000.000000
                             Input             Electricity   279.000000
                                               Water          19.040000
                             Input efficiency  Electricity     0.850000
                                               Water           0.950000
                             Input price       Electricity     0.000033
                                               Water           0.004800
                             Lifetime          Catalyst        3.000000
                             Output efficiency Hydrogen        0.900000
                                               Oxygen          0.900000
                             Output price      Hydrogen        0.010000
                                               Oxygen          0.003000
                             Scale             NaN          6650.000000

                                                               Units  \
Technology           Scenario Variable          Index
Simple electrolysis Base     Capital cost      Catalyst          USD
                             Fixed cost        Rent           USD/yr
                             Input             Electricity   kJ/mole
                                               Water          g/mole
                             Input efficiency  Electricity         1
                                               Water               1
```

```
                                            Input price       Electricity    USD/kJ
                                                              Water        USD/mole
                                            Lifetime          Catalyst           yr
                                            Output efficiency Hydrogen            1
                                                              Oxygen              1
                                            Output price      Hydrogen        USD/g
                                                              Oxygen          USD/g
                                            Scale             NaN           mole/yr

            Notes
Technology           Scenario Variable          Index
Simple electrolysis Base     Capital cost      Catalyst
Al-Ni catalyst.
                             Fixed cost        Rent
                             Input             Electricity
                                               Water
                             Input efficiency  Electricity
                                               Water
                             Input price       Electricity
                                               Water
                             Lifetime          Catalyst     Effective lifetime
of Al-Ni catalyst.
                             Output efficiency Hydrogen
                                               Oxygen
                             Output price      Hydrogen
                                               Oxygen
                             Scale             NaN                Rough estimate
for a 50W setup.
```

[14]:
```python
base_parameters = scenarios.parameters.xs("Base", level=1, drop_level=False)
base_parameters
```

[14]:
```
                                                          Offset       Value  \
Technology           Scenario Parameter
Simple electrolysis Base     Electricity consumption       3  237.00000
                             Hydrogen production           1    2.00000
                             Jobs                          4    0.00015
                             Oxygen production             0   16.00000
                             Water consumption             2   18.08000

                                                             Units Notes
Technology           Scenario Parameter
Simple electrolysis Base     Electricity consumption         kJ
                             Hydrogen production              g
                             Jobs                      job/mole
                             Oxygen production                g
                             Water consumption                g
```

1.5.3 Generate the new scenarios and append them to the previous ones.

[15]:
```
# Iterate over variables and efficiencies.
for variable, index in variables:
    for efficiency in efficiencies:

        # Name the scenario.
        scenario = "Let " + variable + " @ " + index + " = " +␣
↪str(round(efficiency, 3))

        # Alter the base case.
        vary_design = base_design.rename(index={"Base" : scenario}, level=1)
        vary_design.loc[("Simple electrolysis", scenario, variable, index),␣
↪"Value"] = efficiency

        # Keep the parameters the same.
        vary_parameters = base_parameters.rename(index={"Base" : scenario},␣
↪level=1)

        # Append the results to the existing table of scenarios.
        scenarios.designs = scenarios.designs.append(vary_design)
        scenarios.parameters = scenarios.parameters.append(vary_parameters)
```

See how many rows there are in the tables now.

[16]:
```
scenarios.designs.shape
```

[16]:
```
(588, 3)
```

[17]:
```
scenarios.parameters.shape
```

[17]:
```
(210, 4)
```

1.5.4 Compute the results.

[18]:
```
results = scenarios.evaluate_all()
results
```

[18]:
```
  Value  \
Technology          Scenario                                       Variable Index
Simple electrolysis Alternative                                    Cost     Cost
0.181315
                                                                   Metric   Jobs

0.000150
                                                                   Output   Hydrogen

1.950863
                                                                            Oxygen

15.606903
                    Base                                           Cost     Cost
```

```
0.183900
...
...
                    Let Output efficiency @ Oxygen = 0.95  Output   Oxygen
15.206726
                    Let Output efficiency @ Oxygen = 0.975 Cost     Cost
0.180298
                                                           Metric   Jobs
0.000150
                                                           Output   Hydrogen
1.800796
                                                                    Oxygen
15.606903

  Units
Technology          Scenario                               Variable Index
Simple electrolysis Alternative                            Cost     Cost
USD/mole
                                                           Metric   Jobs
jobs/mole
                                                           Output   Hydrogen
g/mole
                                                                    Oxygen
g/mole
                    Base                                   Cost     Cost
USD/mole
...
...
                    Let Output efficiency @ Oxygen = 0.95  Output   Oxygen
g/mole
                    Let Output efficiency @ Oxygen = 0.975 Cost     Cost
USD/mole
                                                           Metric   Jobs
jobs/mole
                                                           Output   Hydrogen
g/mole
                                                                    Oxygen
g/mole

[168 rows x 2 columns]
```

1.5.5 Plot the cost results.

[19]:
```
cost_results = results.xs("Cost", level=3).reset_index()[["Scenario", "Value"]].
↪iloc[2:]
```

[20]:
```
cost_results["Variable"  ] = cost_results["Scenario"].apply(lambda x: re.
↪sub(r'^Let (.*) @ (.*) =.*$', '\\1[\\2]', x))
cost_results["Efficiency"] = cost_results["Scenario"].apply(lambda x: float(re.
↪sub(r'^.*= (.*)$', '\\1', x)))
cost_results["Cost [USD/mole]"] = cost_results["Value"]
```

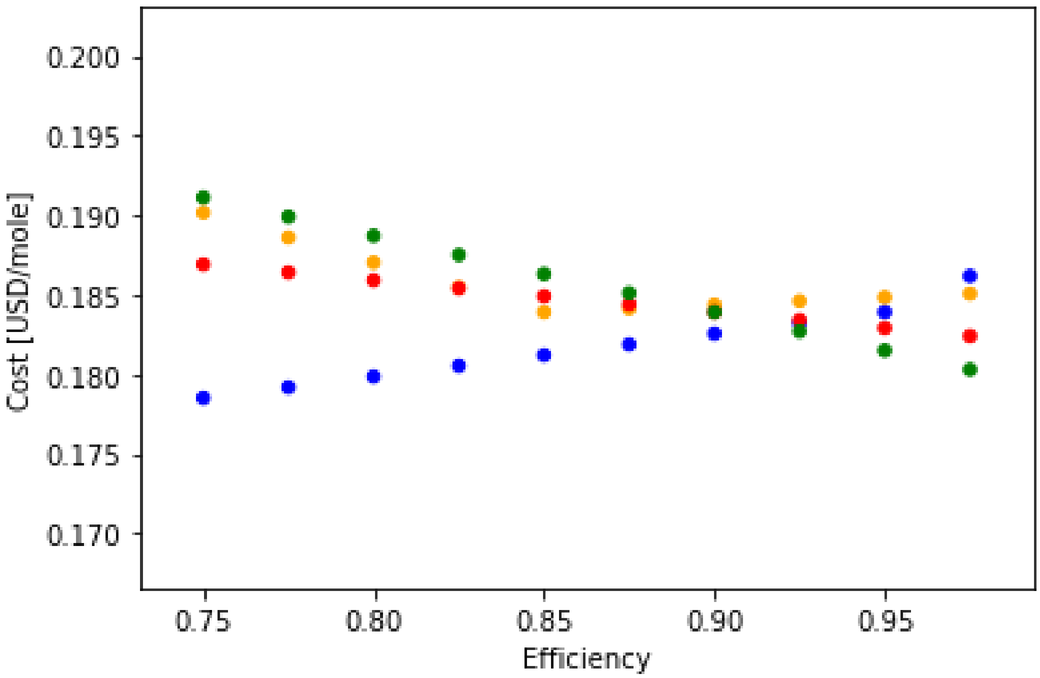
[21]:
```
cost_results = cost_results[["Variable", "Efficiency", "Cost [USD/mole]"]]
cost_results[1:10]
```

[21]:

	Variable	Efficiency	Cost [USD/mole]
3	Input efficiency[Electricity]	0.775	0.188595
4	Input efficiency[Electricity]	0.800	0.187026
5	Input efficiency[Electricity]	0.825	0.185457
6	Input efficiency[Electricity]	0.850	0.183900
7	Input efficiency[Electricity]	0.875	0.184132
8	Input efficiency[Electricity]	0.900	0.184364
9	Input efficiency[Electricity]	0.925	0.184597
10	Input efficiency[Electricity]	0.950	0.184829
11	Input efficiency[Electricity]	0.975	0.185061

[22]:
```
# Here is a really simple plot.
cost_results.plot(
    x="Efficiency",
    y="Cost [USD/mole]",
    c=cost_results["Variable"].apply(lambda v: {
        "Input efficiency[Water]"       : "blue"  ,
        "Input efficiency[Electricity]" : "orange",
        "Output efficiency[Oxygen]"     : "green" ,
        "Output efficiency[Hydrogen]"   : "red"   ,
    }[v]),
    kind="scatter"
)
```

[22]: <matplotlib.axes._subplots.AxesSubplot at 0x7f774f34ab00>


0.200
0.195
0.190
0.185
0.180
0.175
0.170
Cost [USD/mole]
0.75
0.80
0.85
0.90
0.95
Efficiency