ECE 333 – Green Electric Energy

10. Energy Economics Concepts

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The economic evaluation of a renewable energy resource requires a meaningful quantification of the cost elements:
- fixed costs
- variable costs

We use engineering economics notions for this purpose since they provide the means to compare on a consistent basis:
- two different projects; or,
- the costs with and without a given project
Basic underlying notion: a dollar today is not the same as a dollar in a year.

We represent the time value of money by the standard approach of discounted cash flows.

The notation is:

\[ P = \text{principal} \]
\[ i = \text{interest value} \]

We use the convention that every payment occurs at the end of a period.
SIMPLE EXAMPLE

loan $P$ for 1 year
repay $P + iP = P(1 + i)$ at the end of 1 year

year 0 $P$
year 1 $P(1 + i)$

loan $P$ for $n$ years

year 0 $P$
year 1 $(1 + i)P$ repay/reborrow
year 2 $(1 + i)^2 P$ repay/reborrow
year 3 $(1 + i)^3 P$ repay/reborrow

$\vdots$
year $n$ $(1 + i)^n P$ repay
## COMPOUND INTEREST

<table>
<thead>
<tr>
<th>end of period</th>
<th>amount owed</th>
<th>interest for next period</th>
<th>amount owed at the beginning of the next period</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$P$</td>
<td>$P \cdot i$</td>
<td>$P + P \cdot i = P (1 + i)$</td>
</tr>
<tr>
<td>1</td>
<td>$P(1 + i)$</td>
<td>$P(1 + i) \cdot i$</td>
<td>$P(1 + i) + P(1 + i) \cdot i = P(1 + i)^2$</td>
</tr>
<tr>
<td>2</td>
<td>$P(1 + i)^2$</td>
<td>$P(1 + i)^2 \cdot i$</td>
<td>$P(1 + i)^2 + P(1 + i)^2 \cdot i = P(1 + i)^3$</td>
</tr>
<tr>
<td>3</td>
<td>$P(1 + i)^3$</td>
<td>$P(1 + i)^3 \cdot i$</td>
<td>$P(1 + i)^3 + P(1 + i)^3 \cdot i = P(1 + i)^4$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$n-1$</td>
<td>$P(1 + i)^{n-1}$</td>
<td>$P(1 + i)^{n-1} \cdot i$</td>
<td>$P(1 + i)^{n-1} + P(1 + i)^{n-1} \cdot i = P(1 + i)^n$</td>
</tr>
<tr>
<td>$n$</td>
<td>$P(1 + i)^n$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The value in the last column at the e.o.p. $(k-1)$ provides the amount in the first column for the period $k$.
TERMINOLOGY

\[ F = P (1 + i)^n \]

- \( F \) = lump sum repayment at the end of \( n \) periods
- \( P \) = principal amount
- \( i \) = interest rate
- \( n \) = number of periods

- Compound interest in the repayment
- Need not be integer-valued
TERMINOLOGY

- We call \((1 + i)^n\) the **single payment compound amount factor**.

- We define
  \[ \beta \triangleq (1 + i)^{-1} \]

- Then,
  \[ \beta^n = (1 + i)^{-n} \]

  is the **single payment present worth factor**

- \(F\) denotes the **future worth**; \(P\) denotes the **present worth or present value** at interest \(i\) of a future sum \(F\).
EXAMPLE 1

Consider a loan of $4,000 at 8% interest to be repaid in two installments:

- $1,000 and interest at the e.o.y. 1
- $3,000 and interest at the e.o.y. 4

$4,000

$1,000 + interest

$3,000 + interest
EXAMPLE 1

- The cash flows are
  
  - e.o.y. 1: \[ 1,000 + 4,000 \times (0.08) = \$1,320.00 \]
  
  - e.o.y. 4: \[ 3,000 \times (1 + 0.08)^3 = \$3,779.14 \]

- Note that the loan is made in year 0 present $, but the repayments are in year 1 and year 4 future $
EXAMPLE 2

Given

\[ P = 1,000 \quad \text{and} \quad i = .12 \]

then

\[ P \left(1 + i\right)^5 = 1,000 \left(1 + .12\right)^5 = 1,762.34 = F \]

We say that with the cost of money of 12 %, \( P \) and \( F \) are equivalent in the sense that $1,000 today has the same worth as $1,762.34 in 5 years.
EXAMPLE 3

Consider an investment that returns

$1,000 at the e.o.y. 1

$2,000 at the e.o.y. 2

$i = 10\%$

We evaluate $P$

\[
P = \frac{1,000}{1 + .1} + \frac{2,000}{(1 + .1)^2}
\]

\[
= 909.9 + 1,652.09
\]

\[
= 2,561.98
\]
EXAMPLE 3

We review this example with a cash–flow diagram

\[ $2,561.98 \]

\[ $1,000 \]

\[ $2,000 \]

0 1 2

year
EXAMPLE 3

Next, suppose that this investment requires $2,400 now and so at 10% we say that the investment has a net present value given by

\[ NPV = 2,561.98 - 2,400 = 161.98 \]
CASH FLOWS

- A cash–flow is basically a transfer of an amount $A_t$ from one entity to another at the e.o.p. $t$

- We consider the cash–flow set $\{A_0, A_1, A_2, \ldots, A_n\}$

- This set corresponds to the set of the transfers at the end of the periods in $\{0, 1, 2, \ldots, n\}$
CASH FLOWS

- We associate the transfer $A_t$ at the e.o.p. $t$,
  
  $t = 0, 1, 2, \ldots, n$

- The convention for cash flows is
  
  + inflow
  
  - outflow

- Each cash flow requires the specification of:
  
  - amount;
  
  - time; and,
  
  - its sign
Given a cash–flow set \( \{A_0, A_1, A_2, \ldots, A_n\} \) we define the future worth \( F_n \) of the cash flow set at the e.o.y. \( n \) as

\[
F_n = \sum_{t=0}^{n} A_t (1 + i)^{n-t}
\]
Note that each cash flow $A_t$ in the $(n + 1)$ period set contributes differently to $F_n$:

\[
\begin{align*}
A_0 & \rightarrow A_0 (1 + i)^n \\
A_1 & \rightarrow A_1 (1 + i)^{n-1} \\
A_2 & \rightarrow A_2 (1 + i)^{n-2} \\
& \vdots \\
A_t & \rightarrow A_t (1 + i)^{n-t} \\
& \vdots \\
A_n & \rightarrow A_n
\end{align*}
\]
We define the present worth $P$ of the cash-flow set as

$$P = \sum_{t=0}^{n} A_t \beta^t = \sum_{t=0}^{n} A_t (1+i)^{-t}$$

Note that

$$P = \sum_{t=0}^{n} A_t (1+i)^{-t}$$

$$= \sum_{t=0}^{n} A_t (1+i)^{-t} \left(1+i\right)^n \left(1+i\right)^{-n}$$
CASH FLOWS

\[
\beta^n F_n = \left(1 + i\right)^n P
\]
Consider the cash-flow set \( \{ A_1, A_2, \ldots, A_n \} \) with

\[
A_t = A \quad t = 1, 2, \ldots, n
\]

Such a set is called an equal payment cash flow set.

We compute the present worth at \( t = 0 \)

\[
P = \sum_{t=1}^{n} A_t \beta^t = A \sum_{t=1}^{n} \beta^t = A \beta \left[ 1 + \beta + \beta^2 + \ldots + \beta^{n-1} \right]
\]
Now, for $0 < \beta < 1$, we have the identity

$$\sum_{j=0}^{\infty} \beta^j = \frac{1}{1 - \beta}$$

It follows that

$$1 + \beta + \ldots + \beta^{n-1} = \sum_{j=0}^{\infty} \beta^j - \beta^n \left[1 + \beta + \beta^2 + \ldots + \beta^{n-1} + \ldots\right]$$

$$= (1 - \beta^n) \sum_{j=0}^{\infty} \beta^j$$
$\beta = \left(1 + d\right)^{-1}$,

where $d$ is the interest or discount rate and so...
UNIFORM CASH–FLOW SET

\[ 1 - \beta = 1 - \frac{1}{1+d} = \frac{d}{1+d} = \beta d \]

We write

\[ P = A \cdot \frac{1 - \beta^n}{d} \]

and we call \( \frac{1 - \beta^n}{d} \) the equal payment series present worth factor.
We consider two cash-flow sets under a given discount rate $d$.

We say $\{A_t^a: t = 0, 1, 2, \ldots, n\}$ and $\{A_t^b: t = 0, 1, 2, \ldots, n\}$ are equivalent cash-flow sets if and only if

$$F_m \text{ of } \{A_t^a\} = F_m \text{ of } \{A_t^b\} \text{ for every value of } m$$
Consider the two cash-flow sets under $d = 7\%$.
EQUIVALENCE

We compute

\[ P^a = 2,000 \sum_{t=3}^{7} \beta^t = 7,162.55 \]

and

\[ P^b = 8,200.40 \beta^2 = 7,162.55 \]

Therefore, \( \{ A^a_t \} \) and \( \{ A^b_t \} \) are equivalent cash flow sets under \( d = 7\% \)
EXAMPLE

Consider the cash-flow set illustrated below.

We compute $F_8$ at $t = 8$ for $d = 6\%$.
EXAMPLE

\[ F_8 = 300 \left(1 + .06\right)^7 - 300 \left(1 + .06\right)^5 + 200 \left(1 + .06\right)^4 + 400 \left(1 + .06\right)^2 + 200 \]

= $951.56

- We also compute \( P \)
EXAMPLE

\begin{align*}
P &= 300 \left(1 + 0.06\right)^{-1} - 300 \left(1 + 0.06\right)^{-3} + \\
&\quad 200 \left(1 + 0.06\right)^{-4} + 400 \left(1 + 0.06\right)^{-6} + 200 \left(1 + 0.06\right)^{-8} \\
&= \$597.04
\end{align*}

\(\square\) We check that at \(d = 6\%\)

\begin{align*}
F_8 &= 597.04 \left(1 + 0.06\right)^8 = \$951.56
\end{align*}
DISCOUNT RATE

- The interest rate \( i \) is, typically, referred to as the *discount rate* and is denoted by \( d \).

- In the conversion of the future amount \( F \) to the present worth \( P \), we view the *discount rate* as the interest rate that may be earned from the best investment alternative.

- A postulated savings of \( \$10,000 \) in a project in 5 years is worth at present

\[
P = F_5 \beta^5 = 10,000 (1 + d)^{-5}
\]
DISCOUNT RATE

For $d = 0.1$

$$P = $ 6,201,$$

while for $d = 0.2$

$$P = $ 4,019$$

In general, for a specified future worth, the lower the discount factor, the higher the present worth is
We may state this notion slightly differently; the lower the discount factor, the more valuable a future payoff becomes.

The present worth of a set of costs under a given discount rate is called the *life–cycle costs*, an important term in economic assessment studies.
We consider the purchase of two 100–hp motors – a and b – to be used over a 20–year period; the given discount rate is 10%.

The relative merits of a and b are

<table>
<thead>
<tr>
<th>motor</th>
<th>costs ( $ )</th>
<th>load ( kW )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>2,400</td>
<td>79.0</td>
</tr>
<tr>
<td>b</td>
<td>2,900</td>
<td>77.5</td>
</tr>
</tbody>
</table>
EXAMPLE

☐ The motor is used 1,600 hours per year and electricity costs are constant at 0.08 $/kWh

☐ We evaluate yearly energy costs for the two motors

\[
A_t^a = (79.0 \text{ kW})(1600 \text{ h})(0.08 \$/\text{kWh}) = $10,112
\]

\[
t = 1, 2, \ldots, 20
\]

\[
A_t^b = (77.5 \text{ kW})(1600 \text{ h})(0.08 \$/\text{kWh}) = $9,920
\]
We next evaluate the present worth of $a$ and $b$

$$P^a = 2,400 + 10,112 \sum_{t=1}^{20} (1.1)^{-t} = 8.5136$$

$$= $88,489$

$$P^b = 2,900 + 9,920 \sum_{t=1}^{20} (1.1)^{-t} = 8.5136$$

$$= $87,354$
EXAMPLE

- The difference

\[ P^a - P^b = 88,489 - 87,354 = \$1,135 \]

- Therefore, the purchase of motor \( b \) results in the savings of \( \$1,135 \) under the specified 10% discount rate due to the use of the smaller load consumption motor over the 20-year horizon.
Consider a uniform cash–flow set with $n \to \infty$

$$\left\{ A_t = A : t = 0, 1, 2, \ldots \right\}$$

Then,

$$P = A \frac{\left(1 - \beta^n\right)}{d} \xrightarrow{n \to \infty} A \frac{1}{d}$$

For an infinite horizon uniform cash–flow set
We may view $d$ as the *capital recovery factor* with the following interpretation:

For an initial investment of $P$, the amount

$$d \times P = A$$

is recovered annually in terms of returns on the investment $A$. 
INTERNAL RATE OF RETURN

- We consider a cash–flow set

\[ \{ A_t = A : t = 0, 1, 2, \ldots, n \} \]

- The value of \( d \) for which

\[ P - \sum_{t=0}^{n} A_t \beta^t = 0 \]

is called the internal rate of return (IRR)

- The IRR is a measure of how quickly we recover an investment, or stated differently, the speed or rate at which the returns recover an investment.
EXAMPLE: INTERNAL RATE OF RETURN

Consider the following cash-flow set:

\[
\begin{align*}
0 & \quad \$30,000 \\
1 & \quad $6,000 \\
2 & \quad $6,000 \\
3 & \quad $6,000 \\
4 & \quad $6,000 \\
8 & \quad $6,000
\end{align*}
\]
The present value

\[ P = -30,000 + 6,000 \frac{1 - \beta^8}{d} = 0 \]

has the solution

\[ d \approx 12\% \]

The interpretation is that under a 12% discount rate, the present value of the cash-flow set is 0 and so

\[ d \approx 12\% \] is the IRR for the given cash-flow set
Consider an *infinite horizon* simple investment.

Therefore

\[ d = \frac{A}{I} \]

ratio of annual return to initial investment \( I \)
INTERNAL RATE OF RETURN

Consider

\[ I = \$ 1,000 \]
\[ A = \$ 200 \]

and

\[ d = 20\% \]

We interpret that the returns capture 20% of the investment each year, or equivalently that we have a simple payback period of 5 years.
EXAMPLE: EFFICIENT REFRIGERATOR

- A more efficient refrigerator incurs an investment of additional $1,000 but provides $200 of energy savings annually.

- For a lifetime of 10 years, the IRR is computed from the solution of

\[ 0 = -1,000 + 200 \frac{1 - \beta^{10}}{d} \]

or
EXAMPLE: EFFICIENT REFRIGERATOR

\[ \frac{1 - \beta^{10}}{d} = 5 \]

IRR tables show that

\[ \frac{1 - \beta^{10}}{d} \bigg|_{d = 15\%} = 5.02 \]

and so the IRR is approximately 15 %
INFLATION IMPACTS

- Inflation is a general *increase* in the level of prices in an economy; equivalently, we may view inflation as a general *decline* in the value of the purchasing power of money.

- Inflation is measured using prices: different products may have distinct escalation rates.

- Typically, indices such as the *CPI* – the *consumer price index* – use a market basket of goods and
INFLATION IMPACTS

services as a proxy for the entire US economy

- reference basis is the year 1967 with the price of $100 for the basket \( L_0 \)
- in the year 1990, the same basket cost $374 \( L_{21} \)
- the average inflation rate \( j \) is estimated from

\[
(1 + j)^{23} = \frac{374}{100} = 3.74
\]

and so

\[
j = \left(3.74\right)^{\frac{1}{23}} - 1 \approx 0.059
\]
The inflation rate contributes to the overall market interest rate $i$, sometimes called the combined interest rate.

We write, using $d$ for $i$

\[
(1 + d) = (1 + j)(1 + d')
\]

combined interest rate

inflation rate

real interest rate
INFLATION

We obtain the following identities

\[ d' = \frac{d - j}{1 + j} \]

and

\[ j = \frac{d - d'}{1 + d'} \]
We express the cash flow in then current dollars in the set \( \{ A_t: t = 0, 1, 2, \ldots, n \} \)

The following is synonymous terminology:

\[
\text{current} \equiv \text{then current} \equiv \text{inflated} \equiv \text{after inflation}
\]

An indexed or constant–worth cash–flow is one that does not explicitly take inflation into account, i.e.,
CASH – FLOWS INCORPORATING INFLATION

whatever amount in current inflated dollars will

buy the same goods and services as in the

reference year, typically, the year $0$

The following terms are synonymous

$constant \equiv indexed \equiv inflation\ free \equiv before\ inflation$

and we use them interchangeably
We define the set of constant currency flows

\[ \{ W_t : t = 0, 1, 2, \ldots, n \} \]

corresponding to the set

\[ \{ A_t : t = 0, 1, 2, \ldots, n \} \]

with each element \( A_t \) given in period \( t \) currency.
We use the relationship

\[ A_t = W_t \left(1 + j\right)^t \]

or equivalently

\[ W_t = A_t \left(1 + j\right)^{-t} \]

with \( W_t \) expressed in reference year 0 (today’s) dollars
We have

\[ P = \sum_{t=0}^{n} A_t \beta^t \]

\[ = \sum_{t=0}^{n} W_t (i + j)^t (i + d)^{-t} \]

\[ = \sum_{t=0}^{n} W_t (i + j)^t (i + j)^{-t} (i + d')^{-t} \]

\[ = \sum_{t=0}^{n} W_t (i + d' )^{-t} \]
Therefore, the real interest rate $d'$ is used to discount the indexed cash flows.

In summary,

- We discount current dollar cash flow at $d$
- We discount indexed dollar cash flow at $d'$
Whenever inflation is taken into account, it is convenient to carry out the analysis in present worth rather than future worth or on a cash–flow basis.

Under inflation \((j > 0)\), it follows that a uniform set of cash flows \(\{A_t = A: t = 1, 2, \ldots, n\}\) implies a real decline in the cash flows.
EXAMPLE: INFLATION CALCULATIONS

- We consider an annual inflation rate of $j = 4\%$;

the cost for a piece of equipment is assumed
constant for the next 3 years in terms of today’s $\

\[ W_0 = W_1 = W_2 = W_3 = $1,000 \]

- The corresponding cash flows in current $\$ are

\[ A_0 = $1,000 \]
\[ A_1 = 1,000 \left(1 + .04\right) = $1,040 \]
EXAMPLE: INFLATION CALCULATIONS

$$A_2 = 1,000(1 + .04)^2 = \$1,081.60$$

$$A_3 = 1,000(1 + .04)^3 = \$1,124.86$$

- The interpretation of $A_3$ is that under 4% inflation,

  $\$1,125$ in 3 years will have the same value as

  $\$1,000$ today; it must not be confused with the

  present worth calculation
For the motor \( a \) or \( b \) purchase example, we consider the escalation of electricity at an annual rate of \( j = 5 \% \).

We compute the \( NPV \) taking into account the inflation (price escalation of \( 5 \% \)) and \( d = 10 \% \).

Then,

\[
d' = \frac{d - j}{1 + j} = \frac{.10 - .05}{1 + .05} = \frac{.05}{1.05} = 0.04762
\]
The savings of $192 per year are in constant dollars

\[
P_{\text{savings}} = \sum_{t=1}^{20} W_t (1 + d')^{-t} = 0.04762
\]

and so

\[
P_{\text{savings}} = $2,442
\]

The total savings are

\[
P = -500 + P_{\text{savings}} = $1,942
\]

which are larger than those of $1,135 without electricity price escalation.
EXAMPLE: IRR FOR HVAC RETROFIT WITH INFLATION

☐ An energy efficiency retrofit of a commercial site reduces the HVAC load consumption to 0.8 GWh from 2.3 GWh and the peak demand by 0.15 MW.

☐ Electricity costs are 60 $/MWh and demand charges are 7,000 $/(MW−mo) and these prices escalate at an annual rate of \( j = 5 \% \).

☐ The retrofit requires a $500,000 investment today and is planned to have a 15–year lifetime.
EXAMPLE: \textit{IRR FOR HVAC RETROFIT WITH INFLATION}

We evaluate the \textit{IRR} for this project.

The annual savings are

\begin{align*}
\text{energy} & : \left(2.3 - 0.8 \right) \text{GWh} \left(60 \ $ / \text{MWh} \right) = \$ 90,000 \\
\text{demand} & : \left(0.15 \text{ MW} \right) \left(7000 \ $ / (\text{MWh} - \text{mo}) \right) 12\text{mo} = \$ 12,600 \\
\text{total} & : 90,000 + 12,600 = \$ 102,600
\end{align*}

The \textit{IRR} is the value of \(d^\prime\) that results in
EXAMPLE: *IRR FOR HVAC RETROFIT WITH INFLATION*

\[ 0 = -500,000 + 102,600 \frac{1 - (\beta')^{15}}{d'} \]

The table look up produces the \( d' \) of 19% and with inflation factored in, we have

\[
(1 + d) = (1 + j)(1 + d')
\]

\[
= (1.05)(1.19)
\]

\[ = 1.25 \]

resulting in a combined *IRR* of 25%
A capital investment, such as a renewable energy project, requires funds, either borrowed from a bank, or obtained from investors, or taken from the owner’s own accounts.

Conceptually, we may view the investment as a loan that converts the investment costs into a series of equal annual payments to pay back the loan with the interest.
For this purpose, we use a uniform cash–flow set and use the relation

\[ P = A \frac{1 - \beta^n}{d} \]

present equal equal payment series
door worth payment term present worth factor
Therefore, the equal payment is given by

\[ A = P \frac{d}{1 - \beta^n} \]

capital recovery factor

The capital recovery factor measures the speed with which the initial investment is repaid.
An efficiency upgrade of an air conditioner incurs a $1,000 investment and results in annual savings of $200.

The $1,000 is obtained as a 10-year loan repaid at 7% interest.

The repayment on the loan is done as a uniform cash flow:

\[
A = 1,000 \frac{0.07}{1 - \beta^{10}} = $142.38
\]
The annual net savings are

$$200 - 142.38 = 57.62$$

and not only are the savings sufficient to pay back the loan in 10 years, they also provide a yearly surplus of $57.62.

The benefits/costs ratio is

$$\frac{200}{142.38} = 1.4$$
 EXAMPLE: PV SYSTEM

- We consider a 3 – kW PV system whose capacity factor $\kappa = 0.25$

- The investment incurred $10,000 and the funds are obtained as a 20 – year 6 % loan

- The annual loan repayments are

$$A = 10,000 \frac{0.06}{1 - \beta^{20}} = 10,000(0.0872) = \$ 872$$
EXAMPLE: PV SYSTEM

- The annual energy generated is

\[(3)(0.25)(8,760) = 6,570 \text{ kWh}\]

- We can compute the unit costs of electricity for break-even operation to be

\[\frac{872}{6,570} = 0.133 \text{ $ / kWh}\]
The comparison of various alternatives must be carried out on a consistent basis taking into account:

- inflation impacts
- fixed investment costs
- variable costs

The customary approach for cost valuation consists of the following steps:
LEVELIZED BUS – BAR COSTS

- present worthing of all the cash–flow
- determining the equal amount of an equivalent annual uniform cash–flow set
- determination of the yearly total generation

The ratio of the equal amount to the total generation is called the *levelized bus–bar* costs of energy.
EXAMPLE: MICROTURBINE ENGINE

- We consider the economics of a microturbine

  with the characteristics given in the table below

- We calculate

  - annualized fixed costs
  - initial year variable costs
  - inflation impacts
## EXAMPLE: MICROTURBINE ENGINE

<table>
<thead>
<tr>
<th>characteristic</th>
<th>value</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>investment costs</td>
<td>850</td>
<td>$ / kW</td>
</tr>
<tr>
<td>heart rate</td>
<td>12,500</td>
<td>Btu / KWh</td>
</tr>
<tr>
<td>capacity factor</td>
<td>0.7</td>
<td>—</td>
</tr>
<tr>
<td>fuel costs (year 0)</td>
<td>$4.00 \times 10^{-6}$</td>
<td>$ / Btu</td>
</tr>
<tr>
<td>annual fuel escalation rate</td>
<td>6</td>
<td>%</td>
</tr>
<tr>
<td>variable O&amp;M costs</td>
<td>0.002</td>
<td>$ / kWh</td>
</tr>
<tr>
<td>annual investor discount rate</td>
<td>10</td>
<td>%</td>
</tr>
<tr>
<td>fixed charge rate</td>
<td>12</td>
<td>%</td>
</tr>
<tr>
<td>life time</td>
<td>20</td>
<td>y</td>
</tr>
</tbody>
</table>
EXAMPLE: MICROTURBINE ENGINE

- The annualized fixed costs are

\[
\frac{(850 \$/kW)(12 \%)}{(8760 \text{h})(0.70)} = 0.0166 \ \$/kWh
\]

- The initial year variable costs are

\[
A_0 = \left(12.500 \text{Btu/kWh}\right)\left(4 \times 10^{-6} \$/\text{Btu}\right) + 0.002 \ \$/kWh
\]

\[
= 0.052 \ \$/kWh
\]

- We next account for inflation and we compute

\[
d' = \frac{d - j}{1 + j} = \frac{0.1 - 0.06}{1 + 0.06} = 0.037736
\]
The constant uniform cash – flow set with fuel escalation incorporated is

\[ A_0 \cdot \frac{1 - (\beta')^{20}}{d'} = 0.052 \left( 1 - \frac{1}{\frac{1.037736}{0.0037736}} \right)^{20} \]

and the levelized annual costs are
EXAMPLE: MICROTURBINE ENGINE

\[
0.052 \left( \frac{1 - \left( \frac{1}{1.037736} \right)^{20}}{0.0037736} \right) \left( \frac{0.10}{1 - \left( \frac{1}{1.1} \right)^{20}} \right) = 0.0847 \$/kWh
\]

- The levelized bus – bar costs are, therefore,

\[
0.0166 + 0.0847 = 0.1013 \$/kWh
\]