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
TIME VALUE OF MONEY

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

\[ \cdots \]
year $n$ $(1 + i)^nP$ 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>$P_i$</td>
<td>$P + P_i = P(1+i)$</td>
</tr>
<tr>
<td>1</td>
<td>$P(1+i)$</td>
<td>$P(1+i)i$</td>
<td>$P(1+i) + P(1+i)i = P(1+i)^2$</td>
</tr>
<tr>
<td>2</td>
<td>$P(1+i)^2$</td>
<td>$P(1+i)^2i$</td>
<td>$P(1+i)^2 + P(1+i)^2i = P(1+i)^3$</td>
</tr>
<tr>
<td>3</td>
<td>$P(1+i)^3$</td>
<td>$P(1+i)^3i$</td>
<td>$P(1+i)^3 + P(1+i)^3i = P(1+i)^4$</td>
</tr>
<tr>
<td>$\vdots$</td>
<td>$\vdots$</td>
<td>$\vdots$</td>
<td>$\vdots$</td>
</tr>
<tr>
<td>$n-1$</td>
<td>$P(1+i)^{n-1}$</td>
<td>$P(1+i)^{n-1}i$</td>
<td>$P(1+i)^{n-1} + P(1+i)^{n-1}i = P(1+i)^n$</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 end of period $(k-1)$ provides the amount in the first column for the period $k$. 

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TERMINOLOGY

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

- \( F \) = lump sum repayment at the end of \( n \) periods
- \( P \left( 1 + i \right)^n \) = compound interest
- need not be integer-valued

end of \( n \) periods
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

```
\begin{align*}
\$1,000 + \text{interest} \\
\$3,000 + \text{interest}
\end{align*}
```
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 dollars, but the repayments are in year 1 and year 4 future dollars.
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 when the cost of money is 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 $P$

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

\[ \beta \]

\[ \beta^2 \]

\[ = 909.9 + 1,652.09 \]

\[ = 2,561.98 \]
EXAMPLE 3

We review this example with a cash-flow diagram.
Next, suppose that this investment requires $2,400 now and so at 10% we say that the investment has a net present value or

\[ NPV = \$2,561.98 - \$2,400 = \$161.98 \]
A cash–flow is 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 in the periods $\{0, 1, 2, \ldots, n\}$ with the transfer $A_t$ at the e.o.p. $t$, $t = 0, 1, 2, \ldots, n$.
CASH FLOWS

- The convention for cash flows is

  + inflow

  - outflow

- Each cash flow requires the specification of:

  - amount;

  - time; and,

  - 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 the future value $F_n$:

\[
\begin{align*}
A_0 & \rightarrow A_0 (1 + i)^n \\
A_1 & \rightarrow A_1 (1 + i)^{n-1} \\
A_2 & \rightarrow A_2 (1 + i)^{n-2} \\
\vdots & \rightarrow \vdots \\
A_t & \rightarrow A_t (1 + i)^{n-t} \\
\vdots & \rightarrow \vdots \\
A_n & \rightarrow A_n
\end{align*}
\]
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

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

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

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

\[ = \beta^n F_n \]

or, equivalently,

\[ F_n = (1+i)^n P \]
UNIFORM CASH–FLOW SET

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

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

\[
= (1 - \beta^n) \sum_{j=0}^{\infty} \beta^j
\]
UNIFORM CASH–FLOW SET

\[ P = A\beta \frac{1 - \beta''}{1 - \beta} \]

Therefore

\[ \beta = (1 + d)^{-1} \]

But

and so
UNIFORM CASH–FLOW SET

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

We write

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

and we call \[ \frac{1 - \beta^n}{d} \] the equal payment series present worth factor
EQUIVALENCE

- We consider two cash-flow sets

\[
\{ A^a_t : t = 0, 1, 2, \ldots, n \} \text{ and } \{ A^b_t : t = 0, 1, 2, \ldots, n \}
\]

under a given discount rate \( d \)

- We say \( \{ A^a_t \} \) and \( \{ A^b_t \} \) are equivalent cash-flow sets if and only if

\[
F_m \text{ of } \{ A^a_t \} = F_m \text{ of } \{ A^b_t \} \text{ for each value of } m
\]
EQUIVALENCE EXAMPLE

Consider the two cash-flow sets under $d = 7\%$

$\begin{align*}
\text{Set } b &: 8200.40
\end{align*}$
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 $d = 6\%$

```
<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>$300</td>
<td>$200</td>
<td>$400</td>
<td>$200</td>
<td>$300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$d = 6\%$
```
EXAMPLE

\[ F_8 = 300 (1 + .06)^7 - 300 (1 + .06)^5 + 
\]
\[ 200 (1 + .06)^4 + 400 (1 + .06)^2 + 200 \]
\[ = \$951.56 \]

We also compute \( P \)
EXAMPLE

\[ P = 300 (1 + .06)^{-1} - 300 (1 + .06)^{-3} + 
\]
\[ 200 (1 + .06)^{-4} + 400 (1 + .06)^{-6} + 200 (1 + .06)^{-8} \]

\[ = \$597.04 \]

\[ F_8 = 597.04 (1 + .06)^8 = \$951.56 \]

We check that for \( d = 6\% \)
DISCOUNT RATE

- The interest rate $i$ is, typically, referred to as the discount rate and is denoted by $d$.
- In converting the future amount $F$ to the present worth $P$, we can 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
DISCOUNT RATE

- 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.
EXAMPLE

We consider the purchase of two – \( a \) and \( b \) – 100 – hp motors to be used over a 20 – year period; the discount rate is given to be 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>
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:

\[
A^a_t = \left(79.0 \text{ kW}\right)\left(1600 \text{ h}\right)\left(0.08 \$/\text{kWh}\right) = 10,112
\]

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

\[
A^b_t = \left(77.5 \text{ kW}\right)\left(1600 \text{ h}\right)\left(0.08 \$/\text{kWh}\right) = 9,920
\]
EXAMPLE

We next evaluate the present worth of $a$ and $b$

\[ P^a = 2,400 + 10,112 \sum_{t=1}^{20} (1.1)^{-t} \]
\[ = $88,489 \]

\[ P^b = 2,900 + 9,920 \sum_{t=1}^{20} (1.1)^{-t} \]
\[ = $87,354 \]
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 motor over the 20 – year horizon.
INFINITE HORIZON
CASH – FLOW SETS

Consider a uniform cash–flow set with \( n \to \infty \)

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

Then,

\[
P = A \left( \frac{1 - \beta^n}{d} \right) \quad \text{as} \quad n \to \infty \quad \Rightarrow \quad A \frac{1}{d}
\]

For an infinite horizon uniform cash–flow set
INFINITE HORIZON
CASH – FLOW SETS

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

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 investment.
INTERNAL RATE OF RETURN

- We consider a cash–flow set

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

- 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 fast we recover an investment, or stated differently, the speed with or rate at which the returns recover an investment
EXAMPLE: INTERNAL RATE OF RETURN

Consider the following cash–flow set

$30,000

$6,000 $6,000 $6,000 $6,000

$6,000

$30,000

0

1 2 3 4 8
INTERNAL RATE OF RETURN

- 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

\[ d \approx 12\% \text{ is the IRR for the given cash – flow set} \]
Consider an infinite horizon simple investment

Therefore

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

ratio of annual return to initial investment
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 $374 \rightarrow L_{23}$
- the average inflation rate $j$ is estimated from

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

and so

\[
j = (3.74)^{\frac{1}{23}} - 1 \approx 0.059
\]
INFLATION RATE

- The inflation rate contributes to the overall market interest rate $i$, sometimes called the combined interest rate.

- We write, using $d$ for $i$

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

- 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 the set

\[ \{ A_t : t = 0,1,2, \ldots, n \} \] in then current dollars

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
CASH – FLOWS INCORPORATING INFLATION

account, i.e., 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 corresponding to the set

$$\{W_t : t = 0, 1, 2, ..., n\}$$

corresponding to the set

$$\{A_t : t = 0, 1, 2, ..., n\}$$

with each element $A_t$ given in period $t$ currency.
We use the relationship

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

or equivalently

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

with \( W_t \) expressed in reference year 0 (today’s) dollars.
CASH – FLOWS INCORPORATING INFLATION

- 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

☐ Consider an annual inflation rate of \( j = 4 \% \) and 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
MOTOR ASSESSMENT EXAMPLE

- 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,

$$d' = \frac{d - j}{1 + j} = \frac{0.10 - 0.05}{1 + 0.05} = \frac{0.05}{1.05} = 0.04762$$
MOTOR ASSESSMENT

- The savings of $192 per year are in constant dollars

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

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: \textit{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 \$/\(MW \times mo\) 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-\textit{year} lifetime.
EXAMPLE: \textit{IRR FOR HVAC RETROFIT WITH INFLATION}

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

- The annual savings are:
  
  \[
  \text{energy} \, : \, (2.3 - 0.8) \, \text{GWh} \, (60 \, \$ / \text{MWh}) = 90,000 \\
  \]
  
  \[
  \text{demand} \, : \, (0.15 \, \text{MW}) \, (7000 \, \$ / (\text{MWh} - \text{mo})) \, 12\text{mo} = 12,600 \\
  \]
  
  \[
  \text{total} \, : \, 90,000 + 12,600 = 102,600 \\
  \]

- The \textit{IRR} is the value of $d'$ 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
- worth payment term present worth factor
ANNUALIZED INVESTMENT

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.
EXAMPLE: EFFICIENT AIR CONDITIONER

- An efficiency upgrade of an air conditioner incurs a $1,000 investment and results in savings of $200 per year.
- 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.

\[
A = 1,000 \frac{0.07}{1 - \beta^{10}} = \$142.38
\]
EXAMPLE: EFFICIENT AIR CONDITIONER

- 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
  \[ \frac{200}{142.38} = 1.4 \]
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
  \[
  \frac{872}{6,570} = 0.133 \text{ $/kWh}
  \]
LEVELIZED BUS – BAR COSTS

☐ 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 power.
EXAMPLE: MICROTURBINE ENGINE

- We consider the economics of a microturbine with the characteristics given in the table.

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

- The initial year variable costs are
  \[
  A_0 = (12.500 \ Btu/kWh \times 4 \times 10^{-6} \$/Btu) + 0.002 \ \$/kWh
  \]
  \[
  = 0.052 \ \$/kWh
  \]

- We next account for inflation and we compute
  \[
  d' = \frac{d - j}{1 + j} = \frac{0.1 - 0.06}{1 + 0.06} = 0.037736
  \]
EXAMPLE: MICROTURBINE ENGINE

- The constant uniform cash – flow set with fuel escalation incorporated is

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

and the levelized annual costs are
EXAMPLE: MICROTURBINE ENGINE

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

- The levelized bus – bar costs are, therefore,

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