ELG4126- Sustainable Electrical Power Systems- DGD

Economics of Distributed Resources

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DGD 04- 31 Jan, 2013

Winter 2013

REVIEW from DGD 02- Jan 14^{th}

- Simple Payback Period

$$\text{Simple payback} = \frac{\text{Extra first cost } \Delta P(\$)}{\text{Annual savings } S(\$/\text{yr})}$$

- Initial (Simple) Rate-Of-Return

$$\text{Initial (simple) rate of return} = \frac{\text{Annual savings } S\ (\$/\text{yr})}{\text{Extra first cost } \Delta P(\$)}$$

- e.g. a $1000 investment which returned $500 per year would have a two year payback period and 50% rate of return per year.

REVIEW from DGD 02- Jan 14th

- Net Present Value (NPV)

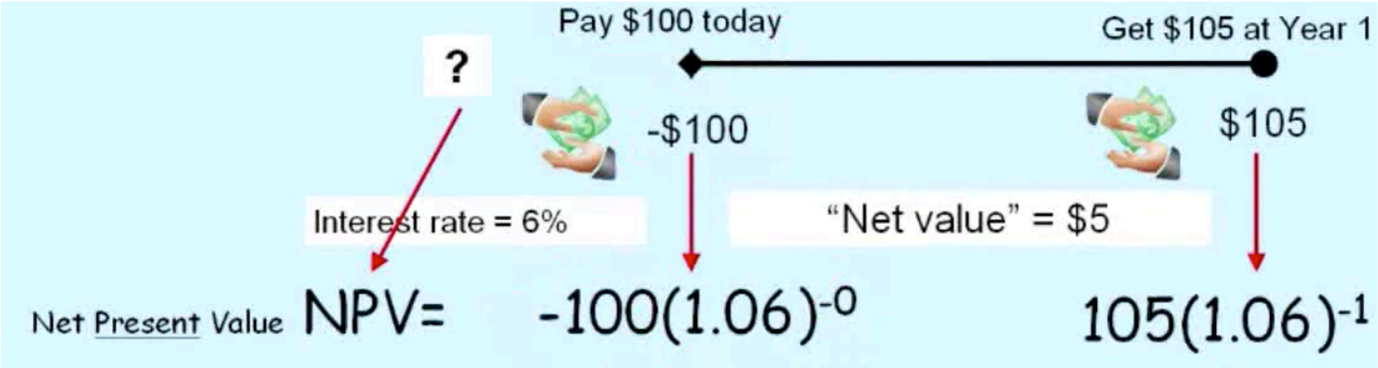
$$F = P\ (1+i)^n \qquad\qquad P = \frac{F}{(1+i)^n}$$

- e.g:

- Net Value: 5$

REVIEW from DGD 02- Jan 14th

- Net Present Value (NPV)



- Assume Bank: interest rate: %6
  - Present value formula at year 1: $\$105(1.06)^{-1}$
  - Present value formula at year 0: $\$100(1.06)^{-0}$

$$NPV= -\$100(1.06)^{-0} + \$105(1.06)^{-1} = -\$0.94$$

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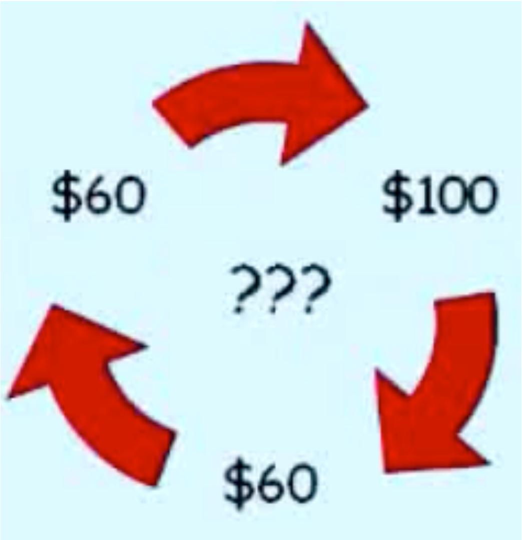
REVIEW from DGD 02- Jan 14th

- Internal Rate of Return (IRR)
- e.g.: rate of return 3%

rate of return?!!?!



$-100(1+r)^{-0}+60(1+r)^{-1}+60(1+r)^{-2}$

IRR: 13%

REVIEW from DGD 02- Jan 14th

- IRR: NPV = ΔA * PVF(IRR, n) – ΔP = 0

$$\text{PVF(IRR, } n) = \frac{\Delta P}{\Delta A} = \text{Simple payback period}$$

Life (years)	9%	11%	13%	15%	17%	19%	21%	23%	25%	27%	29%	31%	33%	35%	37%	39%
1	0.92	0.90	0.88	0.87	0.85	0.84	0.83	0.81	0.80	0.79	0.78	0.76	0.75	0.74	0.73	0.72
2	1.76	1.71	1.67	1.63	1.59	1.55	1.51	1.47	1.44	1.41	1.38	1.35	1.32	1.29	1.26	1.24
3	2.53	2.44	2.36	2.28	2.21	2.14	2.07	2.01	1.95	1.90	1.84	1.79	1.74	1.70	1.65	1.61
4	3.24	3.10	2.97	2.85	2.74	2.64	2.54	2.45	2.36	2.28	2.20	2.13	2.06	2.00	1.94	1.88
5	3.89	3.70	3.52	3.35	3.20	3.06	2.93	2.80	2.69	2.58	2.48	2.39	2.30	2.22	2.14	2.07
6	4.49	4.23	4.00	3.78	3.59	3.41	3.24	3.09	2.95	2.82	2.70	2.59	2.48	2.39	2.29	2.21
7	5.03	4.71	4.42	4.16	3.92	3.71	3.51	3.33	3.16	3.01	2.87	2.74	2.62	2.51	2.40	2.31
8	5.53	5.15	4.80	4.49	4.21	3.95	3.73	3.52	3.33	3.16	3.00	2.85	2.72	2.60	2.48	2.38
9	6.00	5.54	5.13	4.77	4.45	4.16	3.91	3.67	3.46	3.27	3.10	2.94	2.80	2.67	2.54	2.43
10	6.42	5.89	5.43	5.02	4.66	4.34	4.05	3.80	3.57	3.36	3.18	3.01	2.86	2.72	2.59	2.47
15	8.06	7.19	6.46	5.85	5.32	4.88	4.49	4.15	3.86	3.60	3.37	3.17	2.99	2.83	2.68	2.55
20	9.13	7.96	7.02	6.26	5.63	5.10	4.66	4.28	3.95	3.67	3.43	3.21	3.02	2.85	2.70	2.56
25	9.82	8.42	7.33	6.46	5.77	5.20	4.72	4.32	3.98	3.69	3.44	3.22	3.03	2.86	2.70	2.56
30	10.27	8.69	7.50	6.57	5.83	5.23	4.75	4.34	4.00	3.70	3.45	3.22	3.03	2.86	2.70	2.56

REVIEW from DGD 03- Jan 21th

- **NPV and IRR without Fuel Escalation**

$$\mathrm{PVF}(d, n) = \frac{1}{1+d} + \frac{1}{(1+d)^2} + \cdots + \frac{1}{(1+d)^n} = \frac{(1+d)^n - 1}{d(1+d)^n}$$

- **NPV and IRR with Fuel Escalation**
  - *d* is the buyer's discount rate
  - *e* is the escalation rate of the annual savings

$$\mathrm{PVF}(d, e, n) = \frac{1+e}{1+d} + \frac{(1+e)^2}{(1+d)^2} + \ldots + \left(\frac{1+e}{1+d}\right)^n = \frac{(1+d')^n - 1}{d'(1+d')^n}$$

$$\frac{1+e}{1+d} = \frac{1}{1+d'}$$

$$d' = \frac{d-e}{1+e}$$

REVIEW from DGD 03- Jan 21th

- **Finding The IRR When There is Fuel Escalation**

$$\text{NPV} = \Delta A \times \text{PVF}(d', n) - \Delta P \quad = 0$$

$$\text{PVF}(d', n) = \frac{\Delta P}{\Delta A} = \text{Simple payback period}$$

- IRR_0: Internal Rate of Return without Fuel Escalation
- IRR_e: Internal Rate of Return with Fuel Escalation

$$\text{IRR}_0 = \frac{d - e}{1 + e}$$

$$\text{IRR}_e = \text{IRR}_0(1 + e) + e$$

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Example 1. Net Present Value of Premium Motor with Fuel Escalation

- Q: The premium motor costs an extra $500 and saves $192/yr at today's price of electricity. If electricity rises at an annual rate of 5%, find the net present value of the premium motor if the best alternative investment earns 10%. (for 20 years)
- *Answer:*

$$d' = \frac{d-e}{1+e} = \frac{0.10-0.05}{1+0.05} = 0.04762$$

  - The present value function for 20 years of escalating savings is

$$\text{PVF}(d', n) = \frac{(1+d')^n - 1}{d'(1+d')^n} = \frac{(1+04762)^{20} - 1}{0.04762(1+0.04762)^{20}} = 12.717 \text{ yr}$$

  - The net present value is

    NPV = ΔA * PVF(d', n) – ΔP

    NPV = $192/yr * 12.717 yr - $500 = $1942

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Example 2. IRR for an HVAC Retrofit Project with Fuel Escalation

- Q: Suppose the energy-efficiency retrofit of a large building
  - Reduces the annual electricity demand for heating and cooling from $2.3*10^6$kWh to $0.8*10^6$kWh and the peak demand for power by 150 kW
  - Electricity costs $0.06/kWh
  - Demand charges are $7/kW-mo
  - Both of which are projected to rise at an annual rate of 5%.

If the project costs $500,000, what is the internal rate of return over a project lifetime of 15 years?

Example 2. IRR for an HVAC Retrofit Project with Fuel Escalation

- *Answer:* The initial annual savings will be
  - Energy Savings: $(2.3 - 0.8)*10^6$ kWh/yr*$0.06/kWh = $90,000/yr
  - Demand Savings: 150 kW * $7/kW-mo * 12 mo/yr = $12,600/yr
  - Total Annual Savings: ΔA = $90,000 + $12,600 = $102,600/yr
- The Simple payback period will be

$$\text{Simple payback period} = \frac{\Delta P}{\Delta A} = \frac{\$500{,}000}{\$102{,}600/\text{yr}} = 4.87 \text{ yr}$$

- From Table 1, the internal rate of return without fuel escalation IRR_0 is very close to 19%.
- The internal rate of return with fuel escalation is

$$IRR_e = IRR_0(1 + e) + e = 0.19\,(1 + 0.05) + 0.05 = 0.2495 = 25\%/\text{yr}$$

Table 1. Present Value Function to Help Estimate the Internal Rate of Return [a]

Life (years)	9%	11%	13%	15%	17%	19%	21%	23%	25%	27%	29%	31%	33%	35%	37%	39%
1	0.92	0.90	0.88	0.87	0.85	0.84	0.83	0.81	0.80	0.79	0.78	0.76	0.75	0.74	0.73	0.72
2	1.76	1.71	1.67	1.63	1.59	1.55	1.51	1.47	1.44	1.41	1.38	1.35	1.32	1.29	1.26	1.24
3	2.53	2.44	2.36	2.28	2.21	2.14	2.07	2.01	1.95	1.90	1.84	1.79	1.74	1.70	1.65	1.61
4	3.24	3.10	2.97	2.85	2.74	2.64	2.54	2.45	2.36	2.28	2.20	2.13	2.06	2.00	1.94	1.88
5	3.89	3.70	3.52	3.35	3.20	3.06	2.93	2.80	2.69	2.58	2.48	2.39	2.30	2.22	2.14	2.07
6	4.49	4.23	4.00	3.78	3.59	3.41	3.24	3.09	2.95	2.82	2.70	2.59	2.48	2.39	2.29	2.21
7	5.03	4.71	4.42	4.16	3.92	3.71	3.51	3.33	3.16	3.01	2.87	2.74	2.62	2.51	2.40	2.31
8	5.53	5.15	4.80	4.49	4.21	3.95	3.73	3.52	3.33	3.16	3.00	2.85	2.72	2.60	2.48	2.38
9	6.00	5.54	5.13	4.77	4.45	4.16	3.91	3.67	3.46	3.27	3.10	2.94	2.80	2.67	2.54	2.43
10	6.42	5.89	5.43	5.02	4.66	4.34	4.05	3.80	3.57	3.36	3.18	3.01	2.86	2.72	2.59	2.47
15	8.06	7.19	6.46	5.85	5.32	4.88	4.49	4.15	3.86	3.60	3.37	3.17	2.99	2.83	2.68	2.55
20	9.13	7.96	7.02	6.26	5.63	5.10	4.66	4.28	3.95	3.67	3.43	3.21	3.02	2.85	2.70	2.56
25	9.82	8.42	7.33	6.46	5.77	5.20	4.72	4.32	3.98	3.69	3.44	3.22	3.03	2.86	2.70	2.56
30	10.27	8.69	7.50	6.57	5.83	5.23	4.75	4.34	4.00	3.70	3.45	3.22	3.03	2.86	2.70	2.56

[a] Enter the row corresponding to project life, and move across until values close to the simple payback period, $\Delta P/\Delta A$, are reached. IRR is the interest rate in that column. For example, a 10-year project with a 5-year payback has an internal rate of return of just over 15%.

REVIEW from DGD 03- Jan 21th

- **Annualizing the Investment:**
  - A represents annual loan payments ($/yr)
  - P is the principal borrowed ($)
  - i is the interest rate (e.g. 10% corresponds to $i = 0.10$/yr)
  - n is the loan term (yrs), and

$$A = P \times \mathrm{CRF}(i, n)$$

$$\mathrm{CRF}(i, n) = \text{Capital recovery factor}(\mathrm{yr}^{-1}) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

REVIEW from DGD 03- Jan 21th

Capital Recovery Factors as a Function of Interest Rate and Loan Term

Years	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%
5	0.2184	0.2246	0.2310	0.2374	0.2439	0.2505	0.2571	0.2638	0.2706	0.2774	0.2843
10	0.1172	0.1233	0.1295	0.1359	0.1424	0.1490	0.1558	0.1627	0.1698	0.1770	0.1843
15	0.0838	0.0899	0.0963	0.1030	0.1098	0.1168	0.1241	0.1315	0.1391	0.1468	0.1547
20	0.0672	0.0736	0.0802	0.0872	0.0944	0.1019	0.1095	0.1175	0.1256	0.1339	0.1424
25	0.0574	0.0640	0.0710	0.0782	0.0858	0.0937	0.1018	0.1102	0.1187	0.1275	0.1364
30	0.0510	0.0578	0.0651	0.0726	0.0806	0.0888	0.0973	0.1061	0.1150	0.1241	0.1334

Example 3. Comparing Annual Costs to Annual Savings

- Q: An efficient air conditioner that costs an extra $1000 and saves $200 per year is to be paid for with a 7% interest, 10-year loan.
  a. Find the annual monetary savings.
  b. Find the ratio of annual benefits to annual costs.
- *Answer:*
- The capital recovery factor:

$$\mathrm{CRF}(0.07, 10) = \frac{0.07(1+0.07)^{10}}{(1+0.07)^{10}-1} = 0.14238/\mathrm{yr}$$

- The annual payments will be A = $1000 * 0. 14238/yr = $142. 38/yr.

Example 3. Comparing Annual Costs to Annual Savings

a. The annual savings will be \$200 − \$142. 38 = \$57. 62/ yr.
   - Notice that by annualizing the costs the buyer makes money every year so the notion that a 5-year payback period might be considered unattractive becomes irrelevant.

b. The benefit/cost ratio would be

$$\text{Benefit/Cost} = \frac{\$200/\text{yr}}{\$142.38/\text{yr}} = 1.4$$

Example 4. Cost of Electricity from a Photovoltaic System

- Q: A 3-kW photovoltaic system, which operates with a capacity factor (CF) of 0.25, costs $10,000 to install. There are no annual costs associated with the system other than the payments on a 6%, 20-year loan. Find the cost of electricity generated by the system (¢/kWh).

- *Answer:*
  - From Table the capital recovery factor is 0.0872/yr
  - The annual payment:

$$A = P \times \mathrm{CRF}(0.06, 20) = \$10{,}000 \times 0.0872/\mathrm{yr} = \$872/\mathrm{yr}$$

Example 4. Cost of Electricity from a Photovoltaic System

- *Answer:*
  - The annual electricity generated:

(8760 = 365 * 24)

Annual Energy (kWh/yr) = Rated Power (kW) * 8760 hr/yr * CF

Annual energy = 3kW * 8760 h/yr * 0.25 = 6570 kWh/yr

  - The cost of electricity from the PV system is therefore

$$\text{Cost of PV electricity} = \frac{\$872/\text{yr}}{6570\ \text{kWh/yr}} = \$0.133/\text{kWh} = 13.3¢/\text{kWh}$$

DGD04- 31 Jan 2013- Outline

- Energy Economics
  - **Levelized Bus-Bar Codes**
  - Cash Flow Analysis
- Energy Conservation Supply Curves

Levelized Bus-Bar Codes

- To do an adequate **comparison** of **cost per kilowatt-hour** from a renewable energy system versus that for a fossil-fuel-fired power plant, **the potential for escalating future fuel costs** must be accounted for.
- key advantages of the renewable energy systems
  - independence from the uncertainties associated with future fuel costs.
- The cost of electricity per kilowatt-hour for a power plant has two key components
  - an up-front fixed cost to build the plant
  - an assortment of costs that will be incurred in the future

Levelized Bus-Bar Codes

- The usual approach to cost estimation:
  - Finding an **equivalent initial cost**: A present value calculation
  - **Spreading out the amount into a uniform series of annual costs**.
- **The ratio of the equivalent annual cost ($/yr) to the annual electricity generated (kWh/year) is called the *Levelized Bus-Bar* Cost of power**
- *the "bus-bar" refers to the wires as they leave the plant boundaries*
- In the first step, the present value of all future costs must be found, including the impacts of inflation. To keep things simple, we'll assume that the annual costs today are A_0, and that they escalate due to inflation (and other factors) at the rate e. Figure 1 illustrates the concept.

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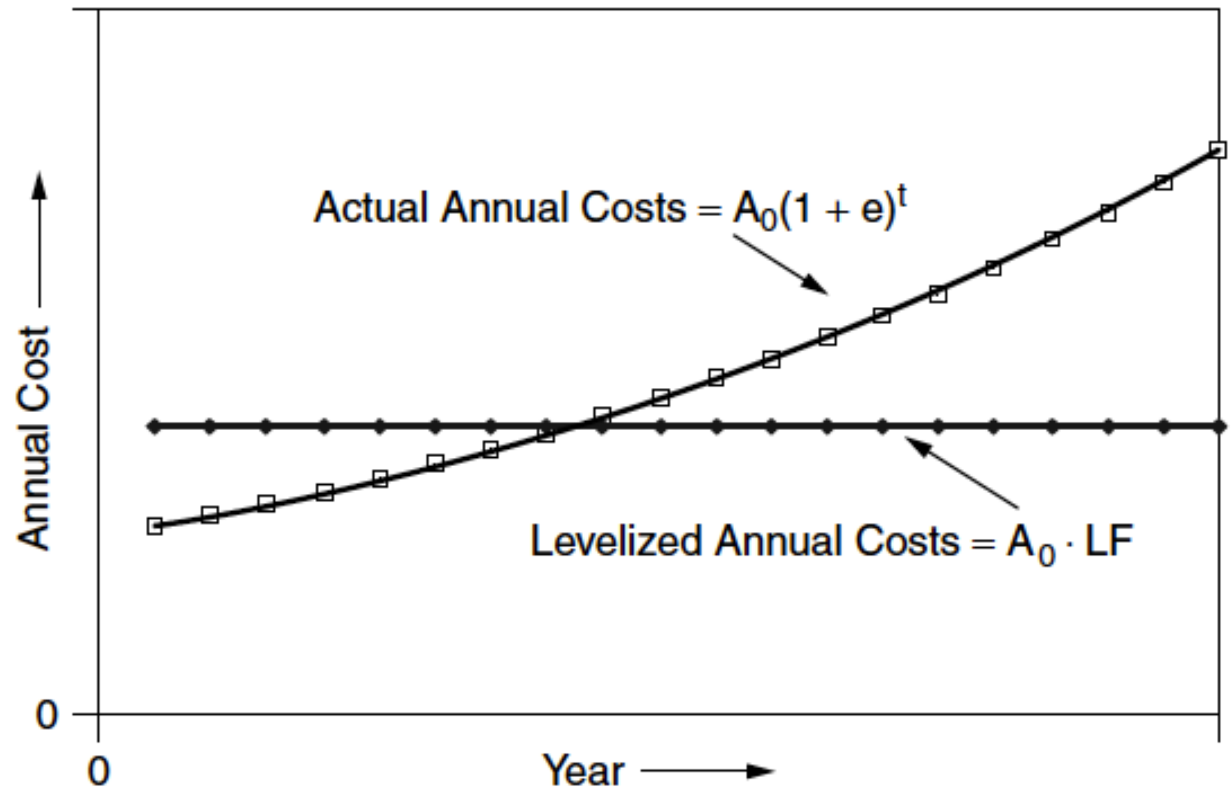
Figure 1. Levelizing annual costs when there is fuel escalation



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Levelized Bus-Bar Codes

- The present value of the escalating annual costs over a period of n years is given by

$$\text{PV(annual costs)} = A_0 \cdot \text{PVF}(d', n)$$

where d' is the equivalent discount rate including inflation introduced in

$$d' = \frac{d - e}{1 + e}$$

Having found the present value of those future costs, we now want to find **an equivalent annual cost** using the capital recovery factor

$$\text{Levelized annual costs} = A_0[\text{PVF}(d', n) \cdot \text{CRF}(d, n)]$$

Levelized Bus-Bar Codes

- The product in the brackets, called the levelizing factor , is a multiplier that converts the escalating annual fuel and O&M costs into a series of equal annual amounts:

$$\text{Levelizing factor (LF)} = \left[\frac{(1+d')^n - 1}{d'(1+d')^n}\right] \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

- Notice that when there is no escalation ($e = 0$), the $d' = d$ and the levelizing factor is just unity!
- The impact of the levelizing factor can be very high, as is illustrated in Figure 2.

Figure 2. Levelizing Factor

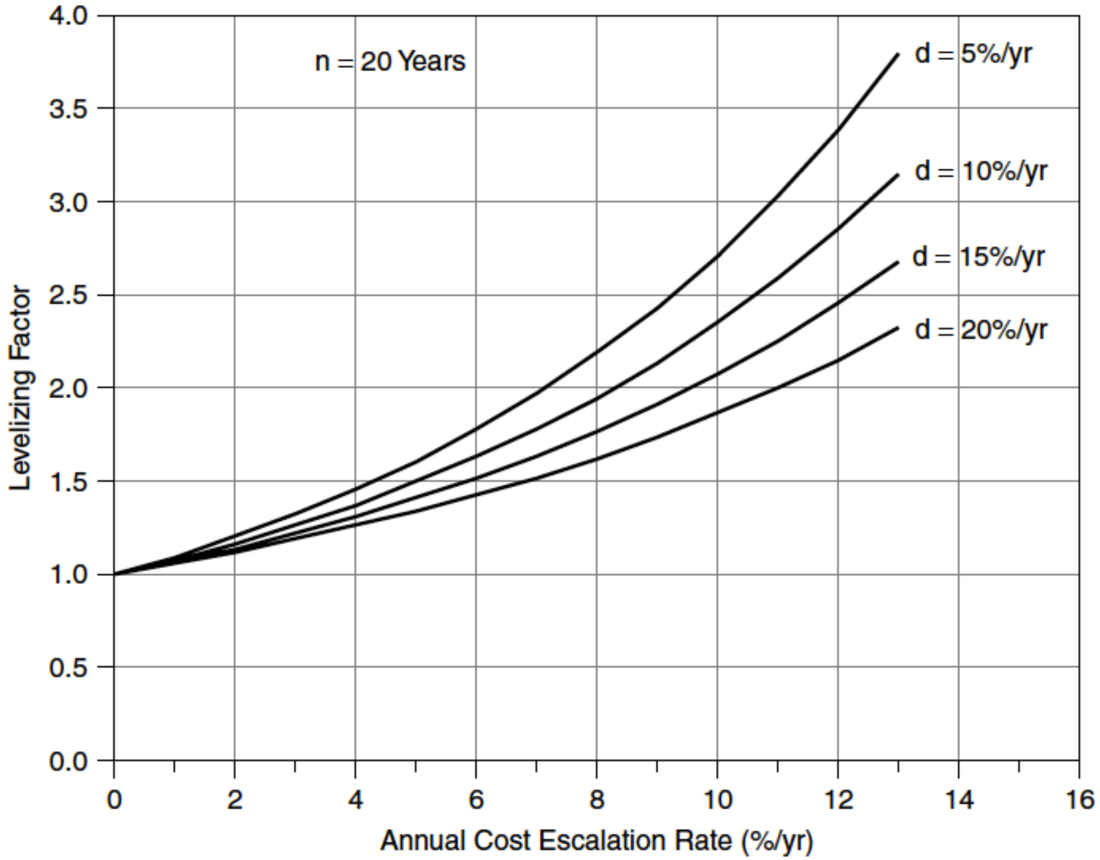

Figure 2. Levelizing Factor

- Levelizing Factor for a 20-year term as a function of the escalation rate of annual costs, with the owner's discount rate as a parameter.
- e.g. if fuel prices increase at 5%/yr for an owner with a 10% discount rate, the levelizing factor is 1.5. If they increase at 8.3%/yr, the impact is equivalent to an annualized cost of fuel that is double the initial cost.
- Normalizing the levelized annual costs to a per kWh basis by using:
  - the heat rate of the plant (Btu/kWh)
  - the initial fuel cost ($/Btu)
  - the per kWh O&M costs
  - the levelizing factor

Levelized Bus-Bar Codes

- Levelized annual costs:

$$\text{Levelized annual costs}(\$/\text{kWh}) = \left[\text{Heat rate}\left(\frac{\text{Btu}}{\text{kWh}}\right) \times \text{Fuel}\left(\frac{\$}{\text{Btu}}\right) + \text{O \& M}\left(\frac{\$}{\text{kWh}}\right)\right]_0 \times \text{LF}$$

Levelized Bus-Bar Codes

- Just as the future cost of fuel and O&M needs to be levelized, so does the **capital cost** of the plant.
- To do so
  - Combine the **CRF** with other costs that depend on the **capital cost** of the plant into a quantity called the ***fixed charge rate (FCR)***
- The fixed charge rate covers costs that are incurred even if the plant doesn't operate, including depreciation, return on investment, insurance, and taxes.
- Fixed charge rates vary depending on plant ownership and current costs of capital, but tend to be in the range of **10–18%** per year.

Levelized Bus-Bar Codes

- The governing equation that annualizes capital costs is then

$$\text{Levelized fixed cost}(\$/\text{kWh}) = \frac{\text{Capital cost}(\$/\text{kW}) \times \text{FCR}(1/\text{yr})}{8760\ \text{h/yr} \times \text{CF}}$$

- Where CF is the capacity factor of the plant
- Table 1 provides estimates for some of the key variables in last two equations.

Table 1. Example Cost Parameters for Power Plants

Technology	Fuel	Capital Cost ($/kW)	Heat Rate (Btu/kWh)	Fuel Cost ($/million Btu)	Variable O&M (¢/kWh)
Pulverized coal steam	Coal	1400	9,700	1.50	0.43
Advanced coal steam	Coal	1600	8,800	1.50	0.43
Oil/gas steam	Oil/Gas	900	9,500	4.60	0.52
Combined cycle	Natural gas	600	7,700	4.50	0.37
Combustion turbine	Natural gas	400	11,400	4.50	0.62
STIG gas turbine	Natural gas	600	9,100	4.50	0.50
New hydroelectric	Water	1900	—	0.00	0.30

Source: Based on data from Petchers (2002) and UCS (1992).

Example 5. Cost of Electricity from a Micro-turbine

- Q: A micro-turbine has the following characteristics:
  - Plant cost = \$850/kW
  - Heat rate = 12,500 Btu/kWh
  - Capacity factor = 0.70
  - Initial fuel cost = \$4.00/10^6 Btu
  - Variable O&M cost = \$0.002/kWh
  - Fixed charge rate = 0.12/yr
  - Owner discount rate = 0.10/yr
  - Annual cost escalation rate = 0.06/yr

Find its levelized (\$/kWh) cost of electricity over a 20-year lifetime

Example 5. Cost of Electricity from a Micro-turbine

- *Answer:*
  - We know:

$$\text{Levelized fixed cost}(\$/\text{kWh}) = \frac{\text{Capital cost}(\$/\text{kW}) \times \text{FCR}(1/\text{yr})}{8760\ \text{h/yr} \times \text{CF}}$$

  - Therefore:

$$\text{Levelized fixed cost} = \frac{\$850/\text{kW} \times 0.12/\text{yr}}{8760\ \text{h/yr} \times 0.70} = \$0.0166/\text{kWh}$$

  - We know: (Levelized annual costs = A_0* LF)

$$\text{Levelized annual costs}(\$/\text{kWh}) = \left[\text{Heat rate}\left(\frac{\text{Btu}}{\text{kWh}}\right) \times \text{Fuel}\left(\frac{\$}{\text{Btu}}\right) + \text{O \& M}\left(\frac{\$}{\text{kWh}}\right)\right]_0 \times \text{LF}$$

Example 5. Cost of Electricity from a Micro-turbine

- Therefore the initial annual cost for fuel and O&M is

A_0=12,500 Btu/kWh * \$400/10^6 Btu + \$0.002/kWh = \$0.052/kWh

This needs to be levelized to account for inflation.

- We know:

$$\text{Equivalent discount rate with fuel escalation} = d' = \frac{d-e}{1+e}$$

- Therefore the inflation adjusted discount rate d would be

$$d' = \frac{d-e}{1+e} = \frac{0.10-0.06}{1+0.06} = 0.037736$$

Example 5. Cost of Electricity from a Micro-turbine

– We know:

$$\text{Levelizing factor (LF)} = \left[\frac{(1+d')^n - 1}{d'(1+d')^n}\right] \cdot \left[\frac{d(1+d)^n}{(1+d)^n - 1}\right]$$

– Therefore we have:

$$\text{Levelizing factor (LF)} = \left[\frac{(1.037736)^{20} - 1}{0.037736(1.037736)^{20}}\right] \cdot \left[\frac{0.10(1.10)^{20}}{(1.10)^{20} - 1}\right] = 1.628$$

– Levelized annual cost:

A_0LF = \$0.052/kWh * 1.628 = \$0.0847

– Levelized fixed plus annual cost:

– Levelized bus-bar cost = \$0.0166/kWh + \$0.0847/kWh = \$0.1013/kWh

DGD04- 31 Jan 2013- Outline

- Energy Economics
  - Levelized Bus-Bar Codes
  - **Cash Flow Analysis**
- Energy Conservation Supply Curves

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Cash Flow Analysis

- One of the most flexible and powerful ways to analyze an energy investment
- This technique easily accounts for complicating factors such as
  - fuel escalation
  - tax-deductible interest, depreciation
  - periodic maintenance costs
  - disposal or salvage value of the equipment at the end of its lifetime.
- The results are computed numerically using **a spreadsheet**
- Each **row** of the resulting table corresponds to ***one year of operation***, and each **column** accounts for a ***contributing factor***

Table 2. Cash-Flow Analysis

Loan principal($) =	1000.00	Energy savings (kWh/yr) =	1500
Interest =	0.06	Price at $t = 0$ (\$/kWh) =	0.10
Loan term (yrs) =	10	Savings at $t = 0$ (\$/yr)	150
CRF(i, n) per yr =	0.13587	Escalating at (%/yr) =	5
Payments (\$/yr) =	135.87		
Tax bracket =	0.305	Personal discount rate =	0.10

End of Year	Loan Payment	Interest	Delta Principal	Loan Balance	Tax Savings	Loan Cost	Electric Savings	Net Savings	PV Savings	Cum PV Savs
0	0.00	0.00	0.00	1000.00	0.00	0.00	0.00	0.00	0.00	0.00
1	135.87	60.00	75.87	924.13	18.30	117.57	157.50	39.93	36.30	36.30
2	135.87	55.45	80.42	843.71	16.91	118.96	165.38	46.42	38.36	74.66
	1000×0.13587	0.06×924.13	$135.87 - 55.45$	$924.13 - 80.42$	0.305×55.45	$135.87 - 16.91$	1.05×157.50	$165.38 - 118.96$	$\frac{46.42}{(1.10)^2}$	$38.36 + 36.30$
9	135.87	14.95	120.92	128.18	4.56	131.31	232.70	101.39	43.00	369.75
10	135.87	7.69	128.18	0.00	2.35	133.52	244.33	110.81	42.72	412.48

Loan paid off (Loan Balance, year 10: 0.00)

PV cumulative savings (Cum PV Savs, year 10: 412.48)

Table 2. Cash Flow Analysis

- Cash-flow analysis for a
  - $1000
  - 6% interest
  - 10-year loan
  - Saves a homeowner $150/yr in electricity (electric saving)
  - The electric saving is expected to increase 5% per year
  - Personal discount factor of 10%.
  - Since this is a home loan, any interest paid on the loan will qualify as a tax deduction

- Year 0:
  - Loan Balance = $1000
- Year 1:
  - CRF(0.06,10)=0.13587
  - Annual Payment = P * CRF = 1000*0.13587=135.87
  - Interest= .06 * $1000 = $60
  - Delta Principle = $135.87 - $60 = $75.87
  - Loan Balance = $1000 - $75.87 = $924.13
- Year 2:
  - Annual Payment = P * CRF = 1000*0.13587=135.87
  - Interest= .06 * $924.13 = $55.45
  - Delta Principle = $135.87 - $55.45 = $80.42
  - Loan Balance = $924.13 - $80.42 = $843.71
- Year 10:
  - Loan Balance = $0

Table 3. Federal Income Tax Brackets for Married Couples Filing Jointly, 2002

Income Over...	But Not Over...	Federal Tax Is...	Of the Amount Over
$0	$45,200	15%	$0
45,200	109,250	$6, 780 + 27.5%	45,200
109,250	166,500	24, 394 + 30.5%	109,250
166,500	297,350	41, 855 + 35.5%	166,500
297,350	—	88, 307 + 39.1%	297,350

- e.g. For a family earning between $109,250 and $166,500, every additional dollar of income has 30.5¢ of taxes taken out of it.
- On the other hand, if the income that has to be reported to the I.R.S. can be reduced by one dollar, that will save 30.5¢ in taxes.
- The 30.5% number is called the ***marginal tax bracket (MTB)***.

Cash Flow Analysis

- Year 1:
  - Tax-deductible interest: $60
  - Buyer's income taxes: $60 * 0.305 = $18.30
  - Loan Cost: $135.87 - $18.30 = $117.57
  - Electricity Savings: $150 * 1.05 = $157.50
  - Total Saving:

    $157.50 (electricity saving) + $18.30 (tax saving) – $135.87(loan payment) = $39.93
  - Personal discount rate: 10%
  - Present Value of Savings: $39.93 / (1.10) = $36.30
  - Cumulative PV Savings: $412.48

Outline

- Energy Economics
  - Levelized Bus-Bar Codes
  - Cash Flow Analysis
- **Energy Conservation Supply Curves**

Energy Conservation Supply Curves

- The convenient and persuasive measure of the **value of saved energy**

- Cost of conserved energy (CCE) has units of \$/kWh, which makes it directly comparable to the \$/kWh cost of generation

$$\text{CCE} = \frac{\text{Annualized cost of conservation}(\$/\text{yr})}{\text{Annual energy saved (kWh/yr)}}$$

Example 6. CCE for a Lighting Retrofit Project

- Q:
  - It typically costs about $50 in parts and labor to put in new lamps and replace burned out ballasts in a conventional four-lamp fluorescent fixture.
  - For $65, more efficient ballasts and lamps can be used in the replacement, which will maintain the same illumination but will decrease the power needed by the fixture from 170 W to 120 W.

  For an office in which the lamps are on 3000 h/yr what is the cost of conserved energy for the better system, if it is financed with a 15-yr, 8% loan, assuming that the new components last at least that long? Electricity from the utility costs 8¢/kWh.

Example 6. CCE for a Lighting Retrofit Project

- *Answer:*
  - The extra cost is \$65 − \$50 = \$15. From Table below, CRF(0.08, 15) is 0.1168/yr so **the annualized cost of the improvement** is

    A = P * CRF (i,n) = \$15 * 0.1168/yr = \$1.75/yr

Years	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%
5	0.2184	0.2246	0.2310	0.2374	0.2439	0.2505	0.2571	0.2638	0.2706	0.2774	0.2843
10	0.1172	0.1233	0.1295	0.1359	0.1424	0.1490	0.1558	0.1627	0.1698	0.1770	0.1843
15	0.0838	0.0899	0.0963	0.1030	0.1098	0.1168	0.1241	0.1315	0.1391	0.1468	0.1547
20	0.0672	0.0736	0.0802	0.0872	0.0944	0.1019	0.1095	0.1175	0.1256	0.1339	0.1424
25	0.0574	0.0640	0.0710	0.0782	0.0858	0.0937	0.1018	0.1102	0.1187	0.1275	0.1364
30	0.0510	0.0578	0.0651	0.0726	0.0806	0.0888	0.0973	0.1061	0.1150	0.1241	0.1334

Capital Recovery Factors as a Function of Interest Rate and Loan Term

Example 6. CCE for a Lighting Retrofit Project

- The **annual energy saved**:

  Saved energy = (170 - 120)W * 3000h/yr ÷ (1000 W/kW) = 150kWh/yr

- The **cost of conserved energy**:

$$CCE = \frac{\$1.75/\text{yr}}{150\ \text{kWh/yr}} = \$0.0117/\text{kWh} = 1.17¢/\text{kWh}$$

- The choice is therefore to spend 8¢ to purchase 1 kWh for illumination or spend 1.17¢ to avoid the need for that kWh.
- In either case, the amount of illumination is the same.

Energy Conservation Supply Curves

- **CCE** provides
  - The measure of the economic benefits of a single efficiency measure for an individual or corporation
  - The great application as a policy tool for energy forecasters by
    - Analyzing a number of efficiency measures
    - Graphing their potential cumulative savings, policy makers
    - Estimating the total energy reduction that might be achievable at a cost less than that of purchased electricity.

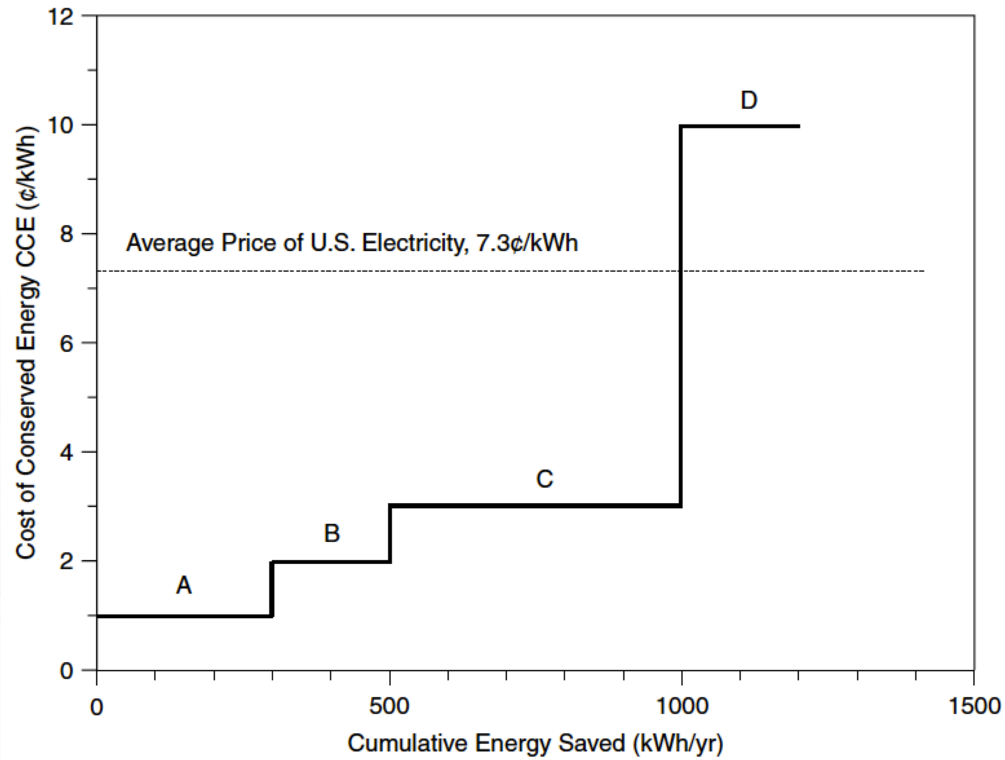
Table 3. Hypothetical Example of Four Independent Conservation Measures

Conservation Measure	CCE (¢/kWh)	Saved Energy (kWh/yr)	Cumulative Energy Saved (kWh/yr)	Cumulative Cost (¢/yr)
A	1	300	300	300
B	2	200	500	700
C	3	500	1000	2200
D	10	200	1200	4200

- e.g. consider four hypothetical conservation measures A, B, C, and D. Suppose they have individual costs of conserved energy and individual annual energy savings values as shown in Table 3.
- If we do Measure A, 300 kWh/yr will be saved at a cost of 1¢/kWh.
- If we do A and B, another 200 kWh/yr will be saved, for a total of 500 kWh/yr.
- All four measures will save 1200 kWh/yr at a total cost of 4200¢/yr

Figure 3. Energy conservation supply curve for the example in Table 1

- A plot of the marginal cost of conserved energy (¢/kWh) versus the cumulative energy saved (kWh/yr) is called an energy conservation supply curve



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Hypothetical Example of Four Independent Conservation Measures

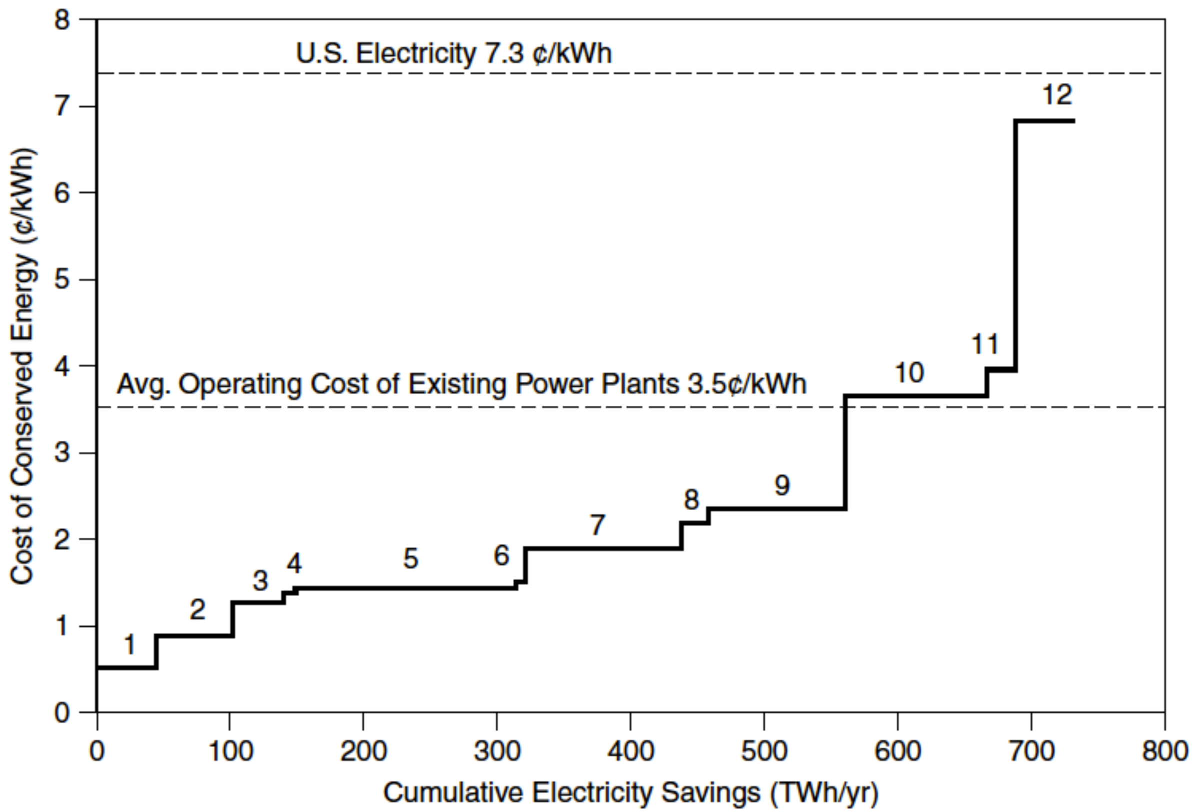
- The average retail price of U.S. electricity at 7.3¢/kWh is also shown on Fig. 3.
- Measures A, B and C each save energy at less than that price, and so they would be cost effective to implement, saving a total of 1000 kWh/yr.
- Measure D, which costs 10¢/kWh, is not cost effective since it would be cheaper to purchase utility electricity at 7.3¢.
- An example of data derived for a real conservation supply curve by the National Academy of Sciences (1992) for U.S. buildings is given in Table 4.

Table 4. Data for an Energy Conservation Supply Curve for U.S. Residential Buildings Calculated Using a Discount Rate of 6 (Real)

	Conservation Measure	CCE $d = 0.06$ (¢/kWh)	Energy Savings (TWh/yr)	Cumulative Savings (TWh/yr)
1	White surfaces and urban trees	0.53	45	45
2	Residential lighting	0.88	56	101
3	Residential water heating	1.26	38	139
4	Commercial water heating	1.37	9	148
5	Commercial lighting	1.45	167	315
6	Commercial cooking	1.50	6	321
7	Commercial cooling	1.91	116	437
8	Commercial refrigeration	2.18	21	458
9	Residential appliances	3.34	103	561
10	Residential space heating	3.65	105	666
11	Commercial and Industrial space heating	3.96	22	688
12	Commercial ventilation	6.83	45	733

Source: National Academy of Sciences (1992).

Figure 4. Electricity conservation supply curve for U.S. buildings (National Academy of Sciences, 1992).



Electricity conservation supply curve for U.S. buildings

- The data from Table 4 have been plotted in the conservation supply curve shown in Figure 4.
- All 12 measures are cost effective when compared to the 7.3¢/kWh average price of electricity in the United States, yielding a total potential savings of 733 billion kWh.
- If all 12 were implemented, they would reduce building electricity consumption by one-third at an average cost of just over 2.4¢/kWh, which is less than the average running cost of U.S. power plants.