ECE 333 – Green Electric Energy

Recitation: Economics Applications

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OUTLINE

- Time value of money
- Net present value
- Internal rate of return
- Inflation impacts
- Total *PV* system cost estimation
- *LCOE* determination of a *PV* system
- The *PV* system tax incentive impacts on the *LCOE*
- The *PV* system tax benefits and rebate program impacts

ENERGY ECONOMICS CONCEPTS

- 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**

$$P \; = \; principal$$

$$i \; = \; interest\ value$$

- **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
$\vdots$	$\vdots$	$\vdots$
year n	$(1+i)^n P$	repay

COMPOUND INTEREST

end of period	*amount owed*	*interest for next period*	*amount owed at the beginning of the next period*
0	P	$P\,i$	$P + P\,i = P(1+i)$
1	$P(1+i)$	$P(1+i)\,i$	$P(1+i) + P(1+i)\,i = P(1+i)^2$
2	$P(1+i)^2$	$P(1+i)^2\,i$	$P(1+i)^2 + P(1+i)^2\,i = P(1+i)^3$
3	$P(1+i)^3$	$P(1+i)^3\,i$	$P(1+i)^3 + P(1+i)^3\,i = P(1+i)^4$
$\vdots$	$\vdots$		
n–1	$P(1+i)^{n-1}$	$P(1+i)^{n-1}\,i$	$P(1+i)^{n-1} + P(1+i)^{n-1}\,i = P(1+i)^n$
n	$P(1+i)^n$		

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

$$F = P\underbrace{(1 + i)^{n}}_{\text{compound interest}}$$

lump sum repayment at the end of n periods

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

CASH FLOWS

- A $\textit{cash-flow}$ 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 $\{0, 1, 2, \ldots, n\}$

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

$$+ \quad inflow$$
$$- \quad outflow$$

- Each cash flow requires the specification of:
  - amount;
  - time; and,
  - sign

EXAMPLE

- Consider an investment that returns

$\$\,1{,}000$ at the *e.o.y.* 1

$\$\,2{,}000$ at the *e.o.y.* 2

$i = 10\%$ ← rate at which money can be freely lent or borrowed

- We evaluate P

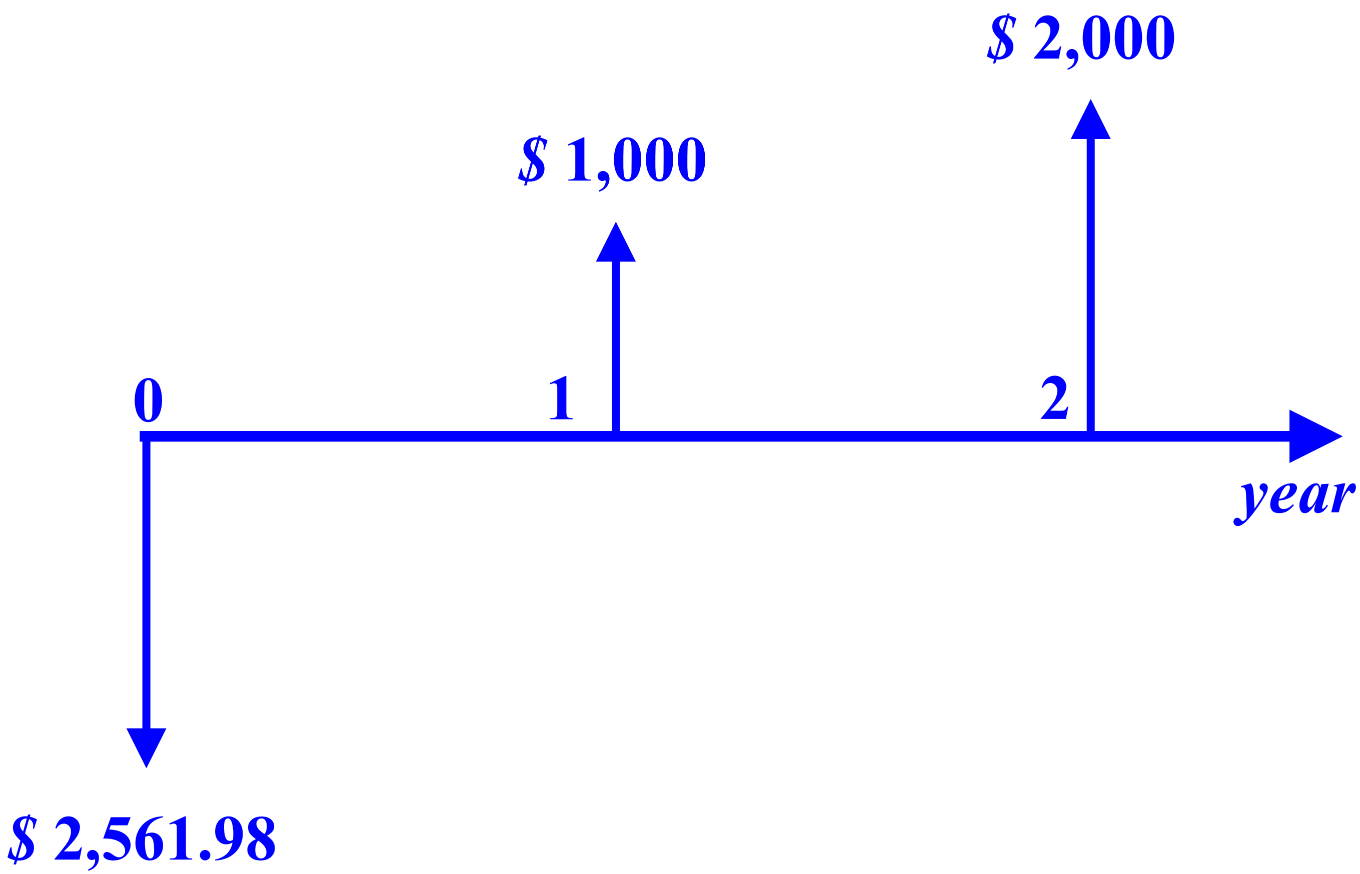
$$P = \$\,1{,}000\underbrace{\left(1+.1\right)^{-1}}_{\beta} + \$\,2{,}000\underbrace{\left(1+.1\right)^{-2}}_{\beta^2}$$

$$= \$\,909.9 + \$\,1{,}652.09$$

$$= \$\,2{,}561.98$$

EXAMPLE

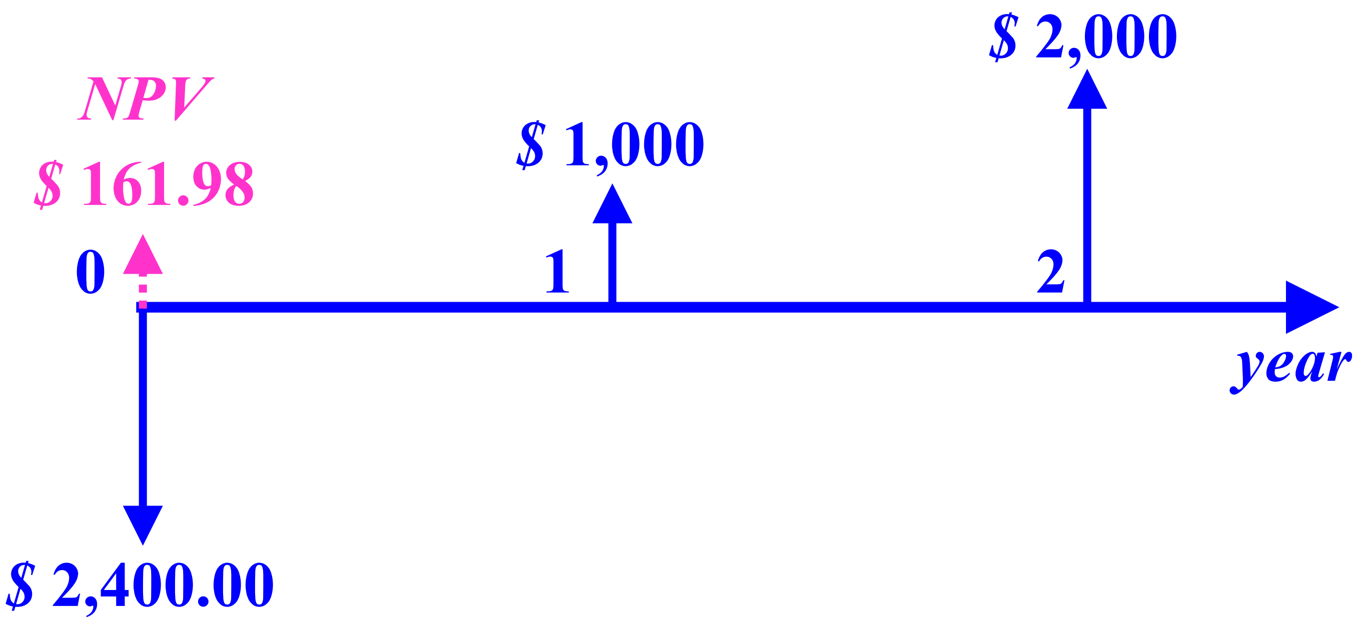
- We review this example with a *cash – flow diagram*



NET PRESENT VALUE

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

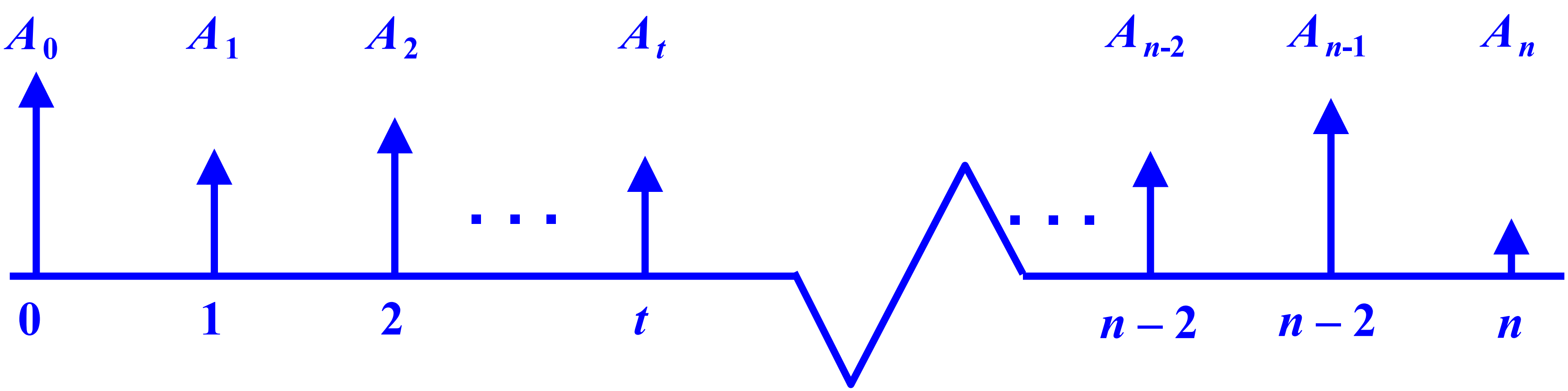
$$NPV = \$\, 2{,}561.98 - \$\, 2{,}400 = \$\, 161.98$$



CASH FLOWS : FUTURE WORTH

- 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

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



CASH FLOWS : FUTURE WORTH

- Note that each cash flow A_t in the $(n+1)$ period set contributes differently to F_n:

$$
\begin{array}{ccc}
A_0 & \rightarrow & A_0\left(1+i\right)^{n} \\
A_1 & \rightarrow & A_1\left(1+i\right)^{n-1} \\
A_2 & \rightarrow & A_2\left(1+i\right)^{n-2} \\
\vdots & & \vdots \\
A_t & \rightarrow & A_t\left(1+i\right)^{n-t} \\
\vdots & & \vdots \\
A_n & \rightarrow & A_n
\end{array}
$$

CASH FLOWS : PRESENT WORTH

- 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

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

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

CASH FLOWS

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

$$= \beta^{n} F_n$$

or, equivalently,

$$F_n = (1+i)^{n} P$$

UNIFORM CASH – FLOW SET

- Consider the cash – flow set $\left\{A_1, A_2, \ldots, A_n\right\}$ with

$$A_t = A \qquad t = 1, 2, \ldots, n$$

- Such a set is called an *equal payment cash flow set*

- We compute the present worth at $t = 0$

$$P = \sum_{t=1}^{n} A_t \beta^t = A \sum_{t=1}^{n} \beta^t = A\beta\left[1 + \beta + \beta^2 + \ldots + \beta^{n-1}\right]$$

UNIFORM CASH–FLOW SET

- Now, for $0 < \beta < 1$, we have the identity

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

- It follows that

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

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

UNIFORM CASH – FLOW SET

$$= \frac{1-\beta^{n}}{1-\beta}$$

- Therefore

$$P = A\beta \frac{1-\beta^{n}}{1-\beta}$$

- But

$$\beta = \left(1+d\right)^{-1}$$

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

$$\left\{ A_t^a : t = 0,1,2, \dots ,n \right\} \text{ and } \left\{ A_t^b : t = 0,1,2, \dots ,n \right\}$$

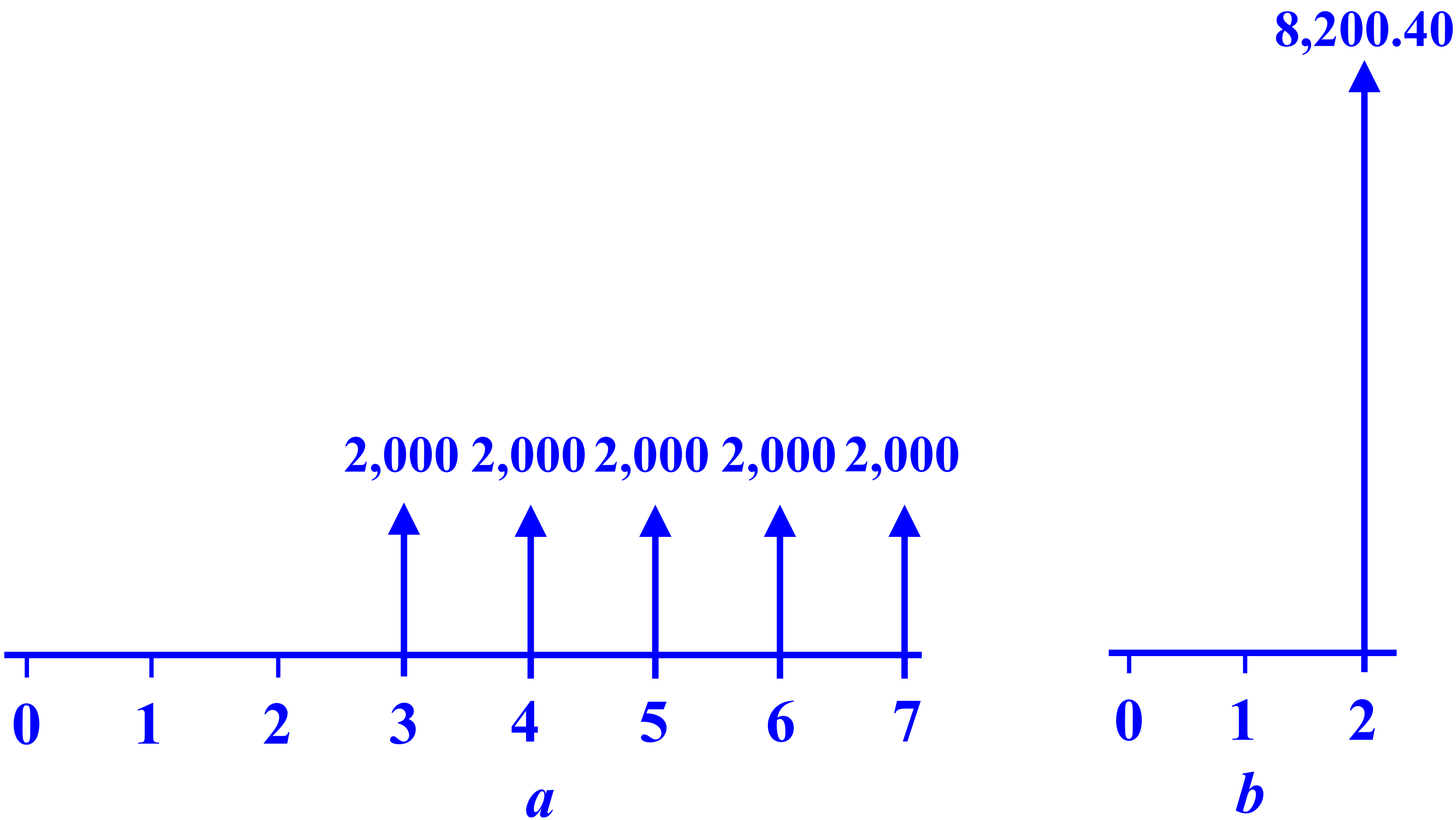
under a given discount rate d

- We say $\left\{ A_t^a \right\}$ and $\left\{ A_t^b \right\}$ are *equivalent* cash – flow sets if and only if

$$F_m \text{ of } \left\{ A_t^a \right\} = F_m \text{ of } \left\{ A_t^b \right\} \text{ for each value of } m$$

EQUIVALENCE EXAMPLE

- 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, $\left\{ A_{t}^{a} \right\}$ and $\left\{ A_{t}^{b} \right\}$ are equivalent cash flow sets under $d = 7\%$

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

$$P = F_5 \beta^5 = 10{,}000 \left(1 + d\right)^{-5}$$

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

INTERNAL RATE OF RETURN

- We consider a cash – flow set

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

- The value of d for which

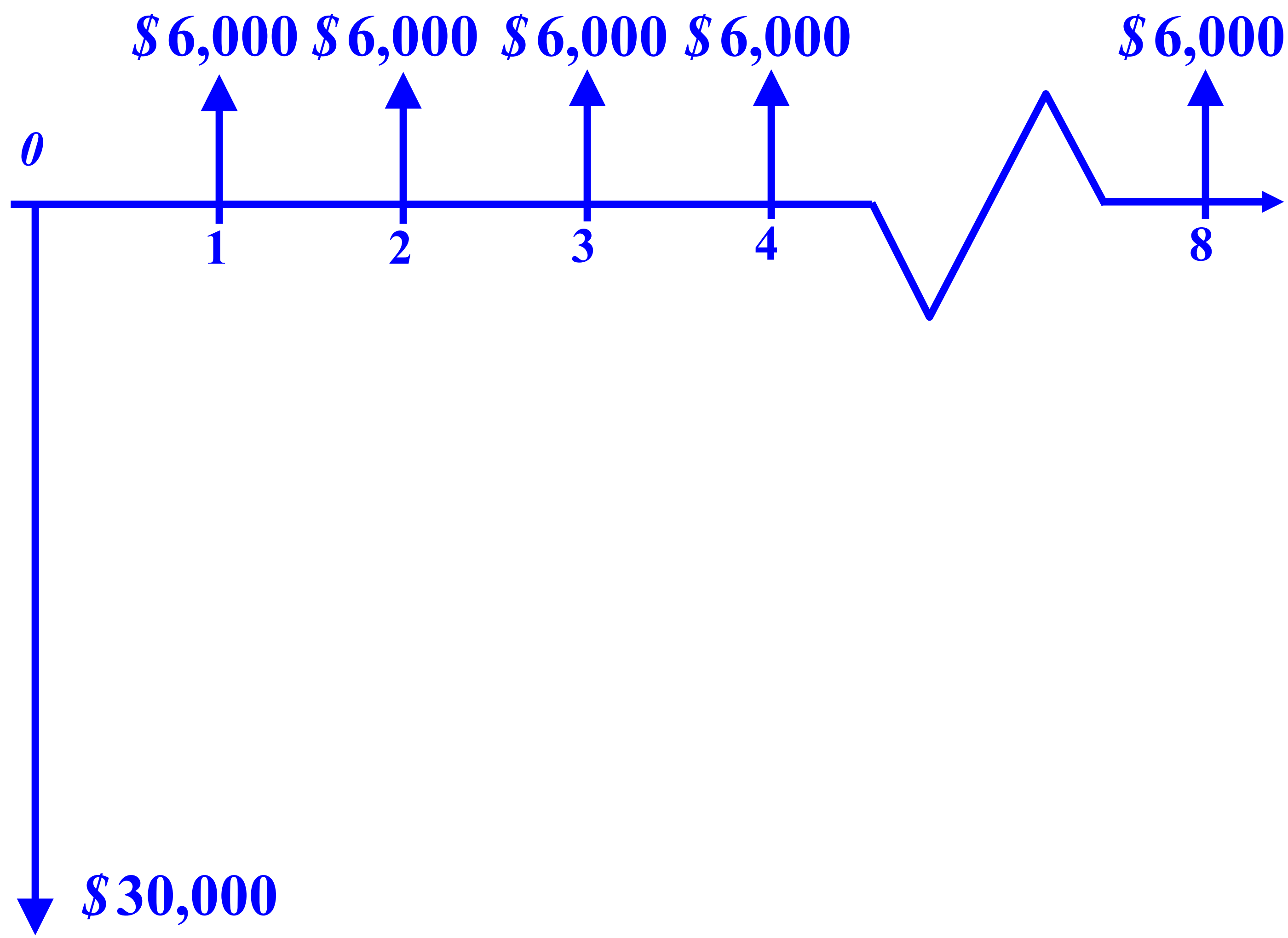
$$P - \sum_{t=0}^{n} A_t \beta^t = 0$$

  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



INTERNAL RATE OF RETURN

- The present value

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

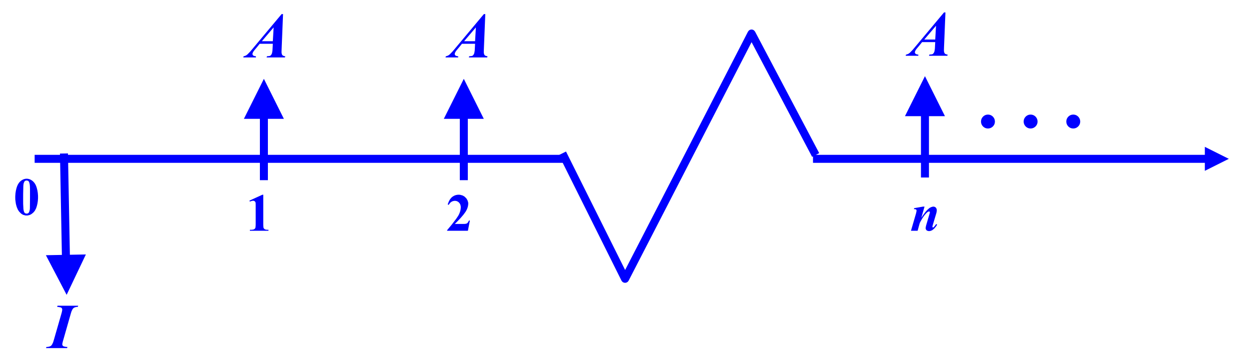
has the solution

$$d \approx 12\%$$

- The interpretation is that under a $12\ \%$ *discount rate*, the *present value* of the cash – flow set is 0 and so $d \approx 12\%$ is the *IRR* for the given cash – flow set

INTERNAL RATE OF RETURN

- 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

IRR TABLE

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

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 $7{,}000\ \$/(MW\text{–}mo)$ 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: *IRR* FOR *HVAC* RETROFIT WITH INFLATION

- We evaluate the *IRR* for this project

- The annual savings are

$$energy \; : (2.3 - 0.8) GWh \left(60 \,\$ / MWh \right) \qquad = \$ \, 90{,}000$$

$$demand : (.15\, MW)(7000 \,\$ / (MWh - mo))12 mo = \$ \, 12{,}600$$

$$total \qquad : 90{,}000 + 12{,}600 = \$ \, 102{,}600$$

- The *IRR* is the value of d' that results in

EXAMPLE: *IRR* FOR *HVAC* RETROFIT WITH INFLATION

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

- The table look up produces the d' of 19 % and

  with inflation factored in, we have

$$\left(1+d\right) = \left(1+j\right)\left(1+d'\right)$$

$$= \left(1.05\right)\left(1.19\right)$$

$$= 1.25$$

  resulting in a combined *IRR* of 25 %

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 $\longrightarrow L_0$
- in the year 1990, the same basket cost $ 374 $\longrightarrow L_{21}$
- 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

$$(1 + d) = (1 + j)(1 + d')$$

combined interest rate — *inflation rate* — *real interest rate*

INFLATION

- We obtain the following identities

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

and

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

CASH – FLOWS INCORPORATING INFLATION

- We express the cash – flow in the set

  $\left\{ A_t : t = 0,1,2, \ldots ,n \right\}$ in then current dollars

- The following is synonymous terminology

  $$current \equiv then\ current \equiv inflated \equiv after\ inflation$$

- 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

$$\textit{constant} \equiv \textit{indexed} \equiv \textit{inflation free} \equiv \textit{before inflation}$$

and we use them interchangeably

CASH – FLOWS INCORPORATING INFLATION

- We define the set of constant currency flows

$$\left\{ W_t : t = 0,1,2, \dots ,n \right\}$$

corresponding to the set

$$\left\{ A_t : t = 0,1,2, \dots ,n \right\}$$

with each element A_t given in period t currency

CASH – FLOWS INCORPORATING INFLATION

- 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

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

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

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

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

CASH – FLOWS INCORPORATING INFLATION

- 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'

CASH – FLOWS INCORPORATING INFLATION

- 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 $\left(j > 0 \right)$, it follows that a uniform set of cash flows $\left\{ A_t = A : t = 1, 2, \ldots, n \right\}$ 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

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

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

- 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,

$$d' = \frac{d - j}{1 + j} = \frac{.10 - .05}{1 + .05} = \frac{.05}{1.05} = 0.04762$$

MOTOR ASSESSMENT

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

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

0.04762

and so

$$P_{savings} = \$\,2,442$$

- The total savings are

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

which are larger than those of $\$\,1,135$ without electricity price escalation

ANNUALIZED INVESTMENT

- **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**

ANNUALIZED INVESTMENT

- For this purpose, we use a uniform cash – flow set and use the relation

$$P = A \underbrace{\frac{1-\beta^{n}}{d}}$$

present worth

equal payment term

equal payment series 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

$$\frac{200}{142.38} = 1.4$$

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

$$A = 10{,}000\ \frac{0.06}{1-\beta^{20}} = 10{,}000\left(0.0872\right) = \$\ 872$$

EXAMPLE: PV SYSTEM

- The annual energy generated is

$$(3)(0.25)(8,760) = 6,570 \; kWh$$

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

$$\frac{872}{6,570} = 0.133 \; \$ / kWh$$

PV SYSTEM TOTAL COST ESTIMATION

- The *PV* system for a Boulder house is designed to generate roughly 4,000 kWh annually
- The key cost components are

component	*costs* ($)
PVs	4.20/W (DC)
inverter	1.20/W (DC)
tracker	$400 + 100/m^2$
installation	3,800

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- We assume the *PV*s have a $12\ \%$ efficiency and the inverter efficiency is $75\ \%$
- We use the solar insolation tables in *Appendix G* to obtain the average daily insolation for a fixed array
- We compare the costs of a fixed array with a -15^{o} tilt angle and those with a *single – axis* tracker

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- The solar insolation tables in *Appendix G* indicate the average daily insolation in Boulder for a fixed array to be 5.4 $kWh/m^2 - d$
- We interpret the insolation as 5.4 h/d of 1 sun
- We compute

$$P_{DC,stc} = \frac{4,000}{(0.75)(5.4)(365)} = 2.71 \; kW_p$$

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- The costs of the *PV*s and the inverters are

$$costs\ of\ PVs = 4.20 \times 2{,}710 = \$\ 11{,}365$$

$$costs\ of\ inverters = 1.20 \times 2{,}710 = \$\ 3{,}247$$

- Given the 12 % efficiency of the *PV*s, the array area required is

$$area = \frac{P_{DC,stc}}{\left(1\, kW / m^2\right)\eta} = \frac{2.71}{1 \times 0.12} = 22.6\, m^2$$

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- We next consider the average daily insolation in Boulder with a *single–axis* tracker of $7.2\ kWh/m^2 - d,$ i.e., $7.2\ h/d$ *of full sun* – as given in *Appendix G*
- We compute

$$p_{DC,stc} = \frac{4,000}{(0.75)(7.2)(365)} = 2.03\,kW_p$$

- The costs of the *PV*s and the inverters are

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

$$costs\ of\ PVs = 4.20 \times 2{,}030 = \$\,8{,}524$$

$$costs\ of\ inverters = 1.20 \times 2{,}030 = \$\,2{,}436$$

- Thus the area for the system is

$$area = \frac{P_{DC,stc}}{\left(1\ kW/m^2\right)\eta} = \frac{2.03}{1 \times 0.12} = 16.9\, m^2$$

- The tracker costs are

$$costs\ of\ trackers = 400 + 16.9 \times 100 = \$\,2{,}090$$

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

element	*fixed tilt array*	*single–axis tracker*
PVs	*$ 11,365*	*$ 8,524*
inverter	*$ 3,247*	*$ 2,436*
tracker	–	*$ 2,090*
installation	*$ 3,800*	*$ 3,800*
total	*$ 18,412*	*$ 16,850*

EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- The installation of the trackers increases the average daily insolation received at the *PV* panels and decreases the area required for the system
- While the trackers add *$* 2,090 to the fixed costs of the *PV* system, the *PV* system investment costs with the trackers are nevertheless markedly below those of the fixed panels

REVIEW OF THE *c.r.f.*

- The *capital recovery factor* is the scheme we use to determine the financing costs of a *PV* project
- A loan of P at interest rate i may be recovered over n years through fixed annual payments of

interest rate

c.r.f.

$$A = P \frac{i}{1-(\beta)^n}$$

$$\beta \triangleq \frac{1}{1+i}$$

EXAMPLE: *LCOE* FOR THE *PV* SYSTEMS

- We illustrate the determination of the *LCOE* with a *PV* system example with the following features:
  - installation costs: $\$ \, 7 \textit{ million}$
  - annual *O&M* costs: $\$ \; 35,000$
  - annual land lease fee: $\$ \; 40,000$
  - annual energy production: 4 *GWh*
  - $9 \; \%, \, 20 - \textit{year}$ loan
- The *c.r.f.* is computed to be

EXAMPLE: *LCOE* FOR THE *PV* SYSTEMS

$$c.r.f.\left(9\,\%,\ 20\,y\right) = \frac{\left(0.09\right)\left(1\ +\ 0.09\right)^{20}}{\left(1+0.09\right)^{20} - 1} = 0.1095\ y^{-1}$$

- The *c.r.f.* results in the annual amortized fixed costs of

$$7{,}000{,}000\ \times\ 0.1095 = \ \$\,766{,}500$$

- Then we can evaluate the *LCOE* using

$$\frac{766{,}500\ +\ 35{,}000\ +\ 40{,}000}{4{,}000{,}000} = 0.21\ \frac{\$}{kWh}$$

FINANCIAL INCENTIVES FOR SOLAR

- A significant factor that was ignored in the cost calculation in the previous example is the impacts of the financial and tax incentives

- Many solar installations are eligible for federal and state tax incentives for the purchase and implementation of PV systems

FEDERAL BUSINESS ENERGY INVESTMENT TAX CREDIT (*ITC*)

State:	Federal
Incentive Type:	Corporate Tax Credit
Administrator:	U.S. Internal Revenue Service
Expiration Date:	Varies by technology, see below
Eligible Renewable/Other Technologies:	Solar Water Heat, Solar Space Heat, Geothermal Electric, Solar Thermal Electric, Solar Thermal Process Heat, Solar Photovoltaics, Wind (All), Geothermal Heat Pumps, Municipal Solid Waste, Combined Heat & Power, Fuel Cells using Non-Renewable Fuels, Tidal, Wind (Small), Geothermal Direct-Use, Fuel Cells using Renewable Fuels, Microturbines
Applicable Sectors:	Commercial, Industrial, Investor-Owned Utility, Cooperative Utilities, Agricultural
Incentive Amount:	30% for solar, fuel cells, small wind* 10% for geothermal, microturbines and CHP
Maximum Incentive:	Fuel cells: $1,500 per 0.5 kW Microturbines: $200 per kW Small wind turbines placed in service 10/4/08 - 12/31/08: $4,000 Small wind turbines placed in service after 12/31/08: no limit All other eligible technologies: no limit

Source: http://programs.dsireusa.org/system/program/detail/658

TAX INCENTIVES FOR SOLAR

- The *ITC* originally enacted in the *Energy Policy Act* of 2005 for solar has been renewed numerous times and is currently set at 30 % of the initial investment

- The *ITC* supports electricity generated by solar systems on residential and commercial properties

EXAMPLE: TAX INCENTIVES FOR SOLAR

- We illustrate the *ITC* impacts on the *LCOE* in the previous *PV* system example

- With the *ITC* , the initial investment tax savings amount to $0.3 \times 7{,}000{,}000 = \$\, 2{,}100{,}000$

- The resulting annual amortized fixed costs are

$$(1-0.3) \times 7{,}000{,}000 \times 0.1095 = \$\, 536{,}550$$

EXAMPLE: TAX INCENTIVES FOR SOLAR

- Then we can evaluate the *LCOE* using

$$\frac{536,550 + 35,000 + 40,000}{4,000,000} = 0.15 \frac{\$}{kWh}$$

- We observe that the introduction of the *ITC* results in a 6 ¢/kWh reduction in the *LCOE*

- This corresponds to a 27 % reduction in the *LCOE*

TAX BENEFITS FOR SOLAR

- **The use of a home loan to finance the installation of a *PV* system has an important impact on the *PV* electricity price in light of the income tax benefits, which depend on the homeowner *marginal tax bracket* (*MTB*)**

TAX BENEFIT FOR SOLAR

- For a loan over several years, almost all of the first year payments constitute the interest due, with a very small contribution to the reduction of the loan principal, while the opposite allocation occurs towards the end of the loan life

- In the first year, interest is owed on the entire amount of the loan and the tax benefits are

$$i \times loan \times MTB$$

EXAMPLE: TAX BENEFIT FOR SOLAR

- Consider a $30-year$ $4.5\,\%$ loan to install a residential $3.36-kW_p$ PV system in Chicago, with the annual energy of $4{,}942\ kWh$

- The $c.r.f.$ for the loan is

$$\frac{(0.045)(1+0.045)^{30}}{(1+0.045)^{30}-1} = 0.06139\ y^{-1}$$

EXAMPLE: TAX BENEFIT FOR SOLAR

- The residential *PV* system costs *$* 19,186 and the annual loan payment is

$$19{,}186 \times 0.06139 = \$1{,}178$$

- Thus the cost of *PV* electricity in the first year is

$$\frac{1{,}178}{4{,}932} = 0.239 \frac{\$}{kWh}$$

- During the first year, the owner pays the annual interest on the *$* 19,186 loan in the amount of

EXAMPLE: TAX BENEFIT FOR SOLAR

$$\textit{first year interest} = 19{,}186 \times 0.045 = \$\,863$$

- We assume the homeowner is in the $25\ \%$ MTB

  and determine the first year tax savings to be

$$863 \times 0.25 = \$\,216$$

  which reduce the cost of PV electricity to

$$\frac{1{,}178 - 216}{4{,}932} = 0.192\,\frac{\$}{kWh}$$

REBATES

- Many states and certain jurisdictions have introduced rebate programs to promote investments in solar systems
- A rebate reduces the total investment required by, in effect, returning some of the costs of the PV system installation to the investor:

$$\textit{reduced costs} = \textit{original costs} - \textit{rebate}$$

ILLINOIS SOLAR AND WIND ENERGY REBATE PROGRAM

Budget:	$2.5 million
Start Date:	12/16/1997
Expiration Date:	10/10/2014 (current applications)
Eligible Renewable/Other Technologies:	Solar Water Heat, Solar Photovoltaics, Wind (All), Solar Pool Heating, Wind (Small)
Applicable Sectors:	Commercial, Industrial, Local Government, Nonprofit, Residential, Schools, State Government, Federal Government
Incentive Amount:	Residential PV: $1.50/watt or 25% of project costs Commercial PV: $1.25/watt or 25% of project costs Nonprofits and Public Sector PV: $2.50/watt or 40% of project costs Residential and Commercial Wind (SWCC certified): $1.75/watt or 30% of project costs Nonprofits and Public Sector Wind (SWCC certified): $2.60/watt or 40% of project costs Wind energy systems that are not SWCC certified: $1.00/watt Residential and Commercial Solar Thermal: 30% of eligible project costs Nonprofits and Public Sector Solar Thermal: 40% of eligible project costs
Maximum Incentive:	Residential: $10,000 Commercial: $20,000 Nonprofits and Public Sector: $30,000
Eligible System Size:	PV systems: Rated design capacity of at least 1 kW; Solar thermal systems: Designed to produce at least 0.5 therms or 50,000 Btus per day or contain at least 60 sq. ft. of collectors Wind: Name-plate capacity 1-100 kW

Source: http://programs.dsireusa.org/system/program/detail/585

EXAMPLE: REBATES

- For instance, if the total investment costs in the previous example are reduced by the 25 % rebate under the Illinois solar and wind energy program, we can determine the reduced annual payment

$$19{,}186 \times (1 - 0.25) \times 0.06139 = \$\,883$$

- Then the first year interest reduces to

EXAMPLE: REBATES

$$19{,}186 \times (1 - 0.25) \times 0.045 = \$648$$

- Therefore the first year tax savings are given by

$$648 \times 0.25 = \$162$$

- Consequently the cost of PV electricity in the first year reduces to

$$\frac{883 - 162}{4{,}932} = 0.146 \frac{\$}{kWh}$$