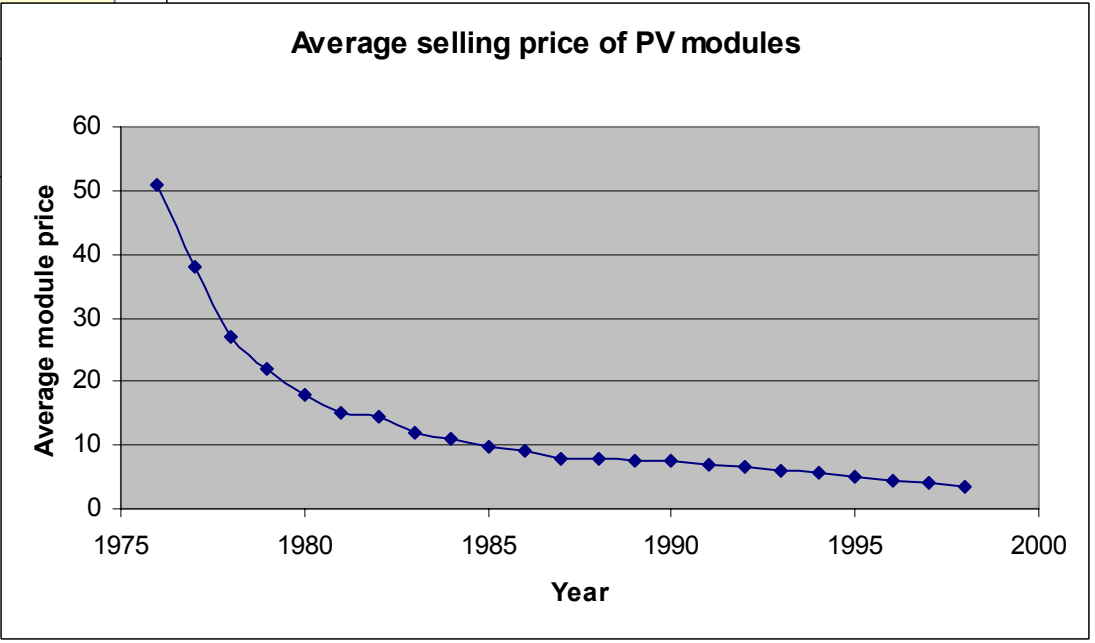
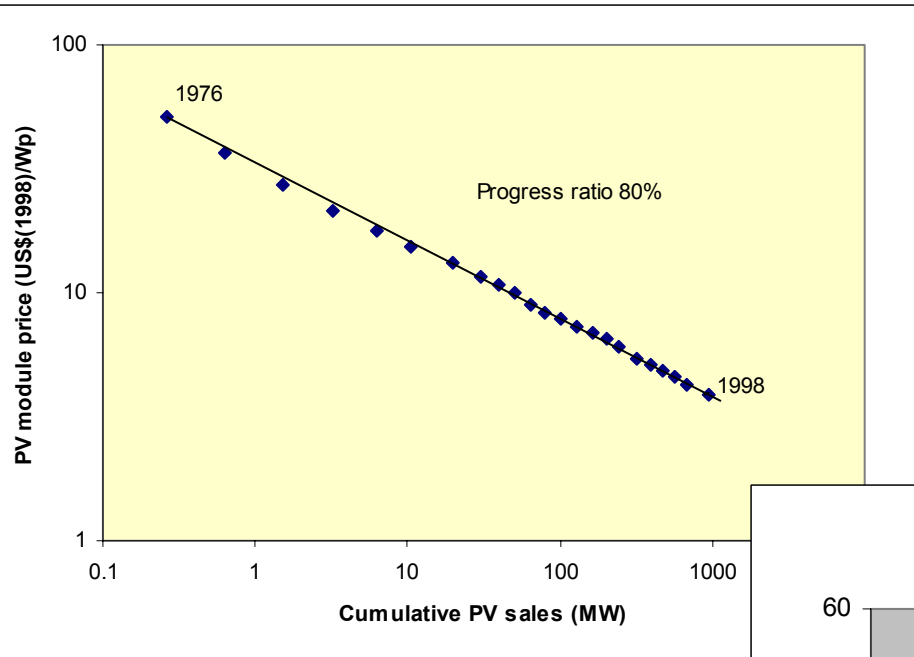


Economic Issues



- Economic issues are a major factor, but do not necessarily give an exact answer – economics often considered in terms of social priorities
- Difficult to do economic comparison accurately because of differences in time frames or assumptions.
- A key issue in economic analysis of power systems is that the value of money is not constant over time.
 1. The “intrinsic value” of money is not constant, but changes with time, reflected by inflation.
 2. Spending money has a cost associated with it.
 - Cost with borrowing money, given by interest rate.
 - Opportunity cost of spending money, specified by discount rate.

Cost Trends



Units of costs: \$/Watt cost

- Module prices are usually quoted in \$/Watt_{peak} (\$/W). This means the cost of the module divided by the power produced by the module under AM1.5 standard conditions.
- The \$/W figure is a number for comparing various solar cell technologies, but should not be used directly in determining the useful power generated by a PV system.
- If the efficiency of the two technologies being compared is radically different, a \$/W figure does not accurately reflect the true cost of electricity from the two types of solar cells and the cost of electricity needs to be used.
- For technologies with similar efficiencies, the lower the \$/W figure, the more desirable the technology. However, the efficiency must be maintained above a certain level.

\$/meter² cost

- Another way of measuring costs is to use \$/m². \$/m² is often useful when looking at the various other material cost components of a PV module which depend on the area used rather than the power produced. For example, the cost of glass is more usefully quoted in terms of \$/m² than \$/Watt.
- The conversion for \$/W to \$/m² is:

$$\frac{\$}{m^2} = \frac{\$}{W} \times \frac{1000W}{m^2} \times \eta = \frac{\$}{W} \times \frac{\text{Watts from module } (W_p)}{\text{Area of module } (A)}$$

- For two technologies with identical \$/W cost, the higher the efficiency module will have the higher the \$/m² cost and hence is more desirable.
- For technologies with different efficiencies, knowing only the \$/m² figure is not enough to effectively compare them.
- Higher efficiency technologies typically have much higher \$/m² figures than lower efficiency, lower cost technologies .

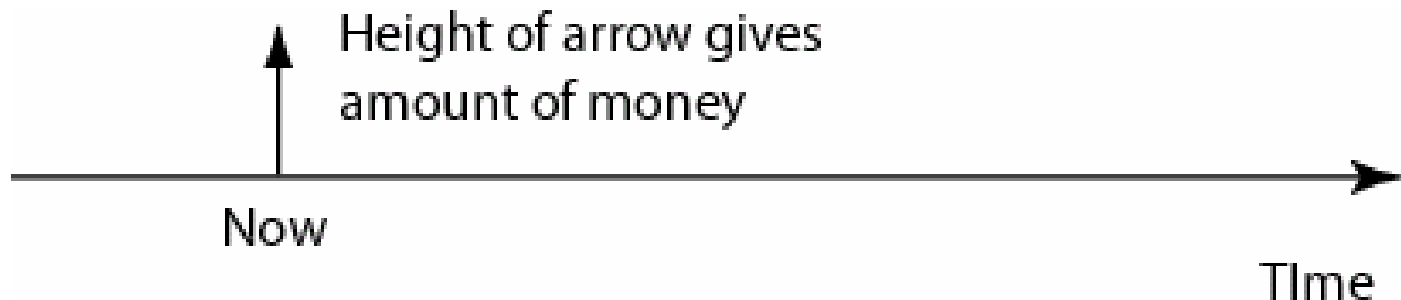
Cost of Electricity

Cost of Electricity (COE)

- Both $\$/W$ and $\$/m^2$ only take into account cost of PV, not other components and system costs.
- Cost of electricity ($\$/kWhr$) takes into account many other factors in a PV system.
- COE is used to compare one type of electricity generating system to another **when the same set of assumptions has gone into both cost analyses.**
- In practical terms, this means that one can only compare COE for different systems if they have been produced by the same author and only ball park figure comparisons can be made for different costing studies.
- Impact of inflation, currency fluctuations, BOS costs, maintenance, etc needs to be taken into account when comparing various costing studies

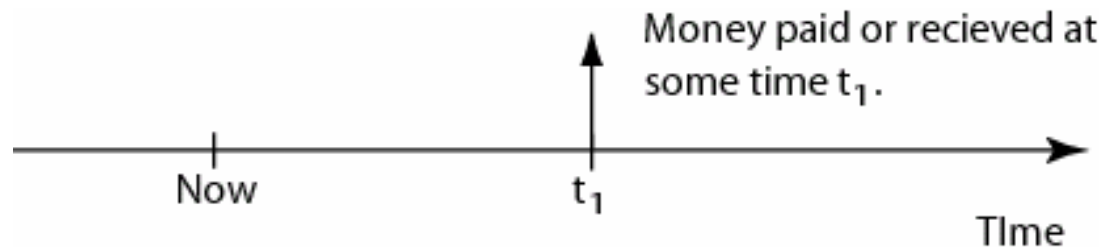
Time Value of Money

- Because costs depend on time at which money is spent, a comparison of costs must convert all expenditures or incomes to the same time frame.
- Commonly used time frames:
 1. Now. In this case, the value of the money is called Net Present Value (NPV) or Present Worth.
 - o Net present value commonly used for decisions in purchasing, comparing costs, etc.
 - o Arrow up indicates received, down indicates payment



Time Value of Money

2. Some specified point in the future, called Net Future Value. This is a single value.
 - Useful for investing or planning calculations – you want to know the future value of you money.



$$\frac{\text{Future Worth}}{\text{Present Worth}} = (F / P, i\%, n) = (1 + i)^n$$

$$\frac{\text{Present Worth}}{\text{Future Worth}} = (P / F, i\%, n) = \frac{1}{(1 + i)^n}$$

Where i is the interest rate and n is the payment period

Time Value of Money



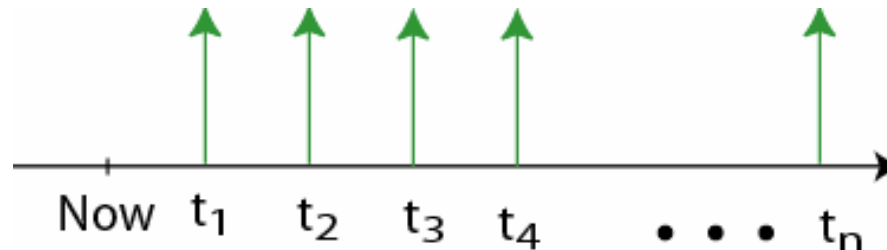
3. Some time in the past

- When using historical costs, can use money as it was valued at that time. This is often called nominal dollars or real dollars or constant dollars.
- Can correct each historical data point to some other year's currency. In this case, it is called real or constant dollars, and the year to which it is normalized must be given.
- In order to correct, need to know the historical inflation or consumer price index (CPI) for that particular currency.

Time Value of Money

4. A series of repeating payments

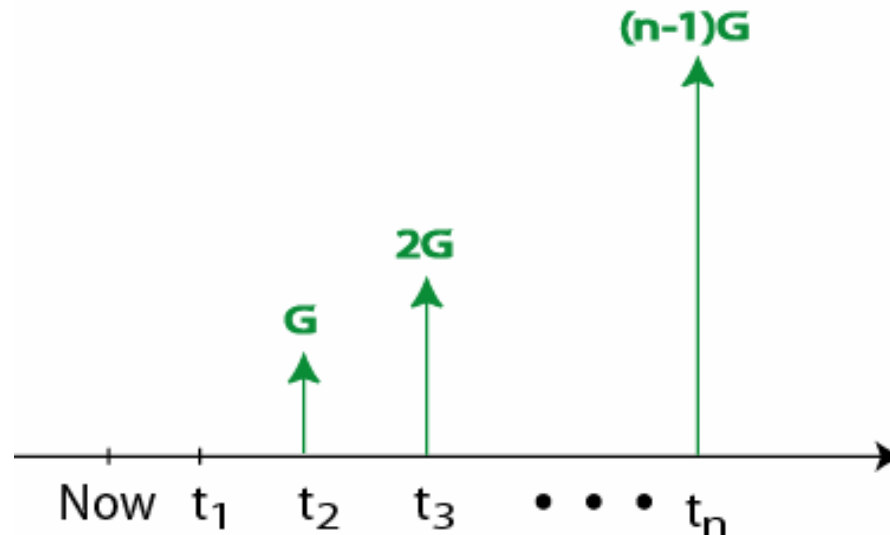
- Repeating payments used in several types of cases: Payback of loans, ongoing costs, sinking fund, capital recovery
 - Payments may either be constant or increasing.
- Can convert a single payment to a series of payments. This is called amortized or annualized.



$$\frac{\text{Annualized}}{\text{Present Worth}} = (A/P, i\%, n) = \frac{i(1+i)^n}{(1+i)^n - 1}$$

Time Value of Money

- Payments may increase arithmetically (increases by a fixed amount each period)

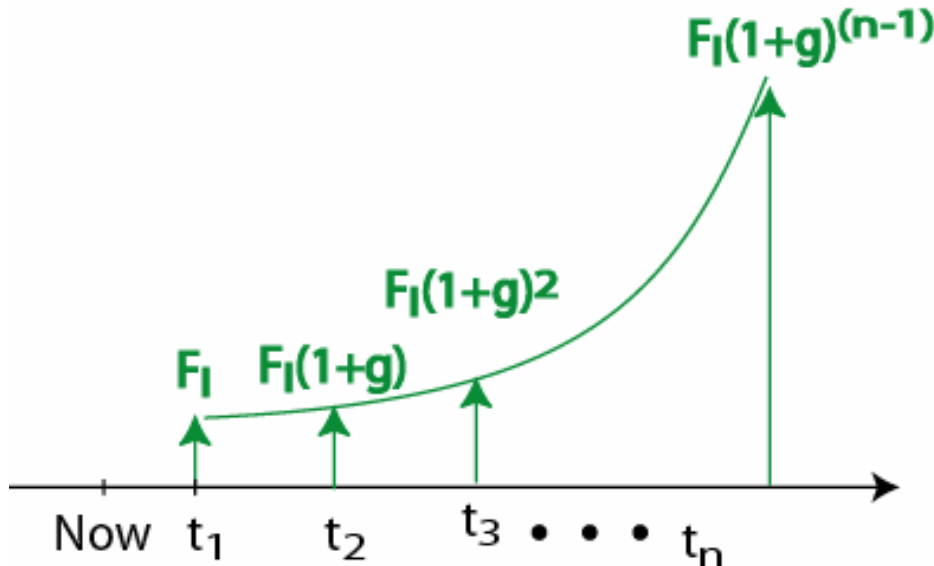


Note that the t_1 value is zero.

$$\frac{\text{Present Worth}}{\text{Arithmetic Gradient}} = (P / G, i\%, n) = \frac{(1+i)^n - in - 1}{i^2 (1+i)^n}$$

Time Value of Money

- Payments may increase geometrically, which increases by a percentage each time interval.
 - Example: electricity cost increase 4% per year.



$$\frac{\text{Present Worth}}{\text{Geometric Gradient}} = (A / F_1, i\%, n) = \frac{(1+i)^n - (1+g)^n}{(1+i)^n (i-g)} \quad i \neq g$$

$$\frac{\text{Present Worth}}{\text{Geometric Gradient}} = (A / F_1, i\%, n) = \frac{n}{(1+i)} \quad i = g$$

Rates Affecting Time Value of Money

- The rate used to calculate how the net value of money depends on what you are doing with the money.
 - Interest rate: Applies to borrowing (lending) money.
 - This is the rate that you are charged (or get) per year to borrow a certain amount of money.
 - Practically, the interest rate is related to inflation rate.
 - Any money that is borrowed (or earned) must be corrected for the inflation rate.
 - Interest can be compounded or simple: in compounding, the interest earned in one period earns interest in the next.
 - If the interest rate is different from the compounding rate, need to calculate effective rate:

$$i_a = \left(1 + \frac{r}{m}\right)^m - 1$$

Where r is the simple interest rate and m is the compounding period

Rates Affecting Time Value of Money

- Inflation rate:
 - Gives how the value of money changes over time.
 - Inflation rate usually used to correct Net Future Value into a Net Present Value (NPV).
 - Several different ways to measure inflation: most common in change in the consumer price index.
- Discount rate.
 - This is the effectively the rate you COULD get if you invested the money rather spending it.
 - Discount rates used to determine if an investment is worthwhile.
- Internal Rate of return
 - The internal rate of return is often used to determine if a particular investment is worthwhile.

Rates in Time Value of Money



- Inflation, interest and discount rates will affect the difference between present and future payments.
 - High values of inflation rate:
 - Favors spending money and having a fixed value asset (unless you have to borrow money).
 - High interest rates
 - Does not favor borrowing money – systems with high initial costs are at a disadvantage
 - High discount rates
 - Place a greater value of having cash than having a particular asset.
 - Discount rates are often set as policy by an organization or institution.

Cost of Electricity

- The cost of electricity is the total cost of the system over its lifetime (usually its NPV) divided by the total energy produced during its lifetime
- Total Costs
 - Initial costs (may attract interest, et)
 - Maintenance costs
 - Recurring costs
 - Salvage value
- Initial costs
 - Consist of cost of the components, land, installation.
 - Some cost scale with amount of power, some scale with space (usually in renewable energy systems).

Cost of Electricity

- Maintenance and operating costs
 - will typically increase throughout the life of the system, but in systems where the maintenance cost is low compared to others, this effect may often be ignored
 - Maintenance cost usually low in renewable energy systems.
 - Typically high for conventional fossil or nuclear plants.
 - For conventional systems, these costs can be very difficult to estimate over the life of the system, since this requires a prediction about the future costs of fuels, labor, etc.

Cost of Electricity

- Recurring costs
 - Usually involve payments for replacement items on a regular basis.
- Salvage value
 - The total costs are the costs expended over the life of the system, minus the value at the end of the life of the system.
 - Often, the salvage value is close to zero for many energy generating systems due to their long life.
 - Instead of having salvage value, some systems may have large costs at end of life.
 - When the end of life costs are high compared to other costs, the cost of electricity becomes highly sensitive to information furthest away from the present – I.e., the least accurate assumptions.

Cost of Electricity

- Most appropriate way to compare cost is to do lifecycle costing, where all the costs are added up, scaled back to the same time frame.
 - The COE is then the total electricity produced divided by the total cost.
- Sensitivity of costing
 - The sensitivity of the cost of electricity is often highly dependant on assumptions of inflation, discount rates.
 - Operating costs, which do not have a large dependence on assumptions, are often compared, but also can be misleading

Finding COE

- Find total costs of PV system over life of system
 - Initial costs (costs of modules, inverter batteries, wiring, installation, mounting, loads, etc)
 - Installation costs
 - Future costs need to be rated at a different “value”
 - Ongoing costs (battery replacement, fuel costs)
 - Maintenance costs
 - Operational costs
 - Repair costs
 - Replacement costs
- Determine life of system
 - Generally is assumed to be at least the warranty period.

Finding COE

- Find costs associated with borrowing & using money
 - Interest rate: cost of borrowing money. High values are detrimental to PV, since it is a capital intensive type of energy (generally 90% initial costs, 10% ongoing costs)
 - Inflation rate: takes into account fluctuations in “value” of money. High rates generally favourable to PV.
 - Discount factor (rate): This is different to inflation. Discount factor accounts for the fact that if the money is spent now, it can't be invested later. Large discount factors mean that low value is placed on future costs and benefits, and high value is placed on present capital. Since PV is capital intensive, high values detrimental to system PV systems. Discount factor depends on interest rate and inflation rate.
 - Ongoing costs may have a different lifetime, interest rates, etc than initial system costs
- Pay back period will in general be lifetime of PV system

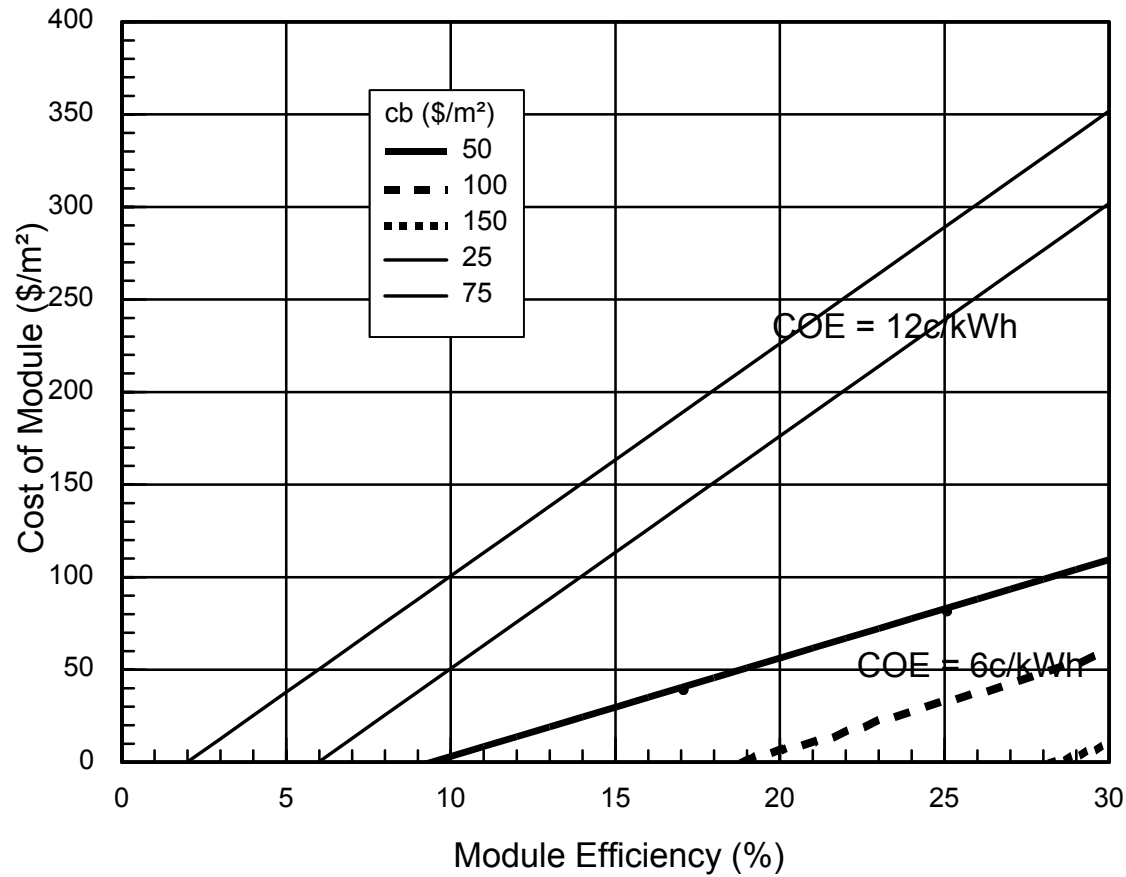
Cost of Electricity

- $COE = [(\text{Annualized Cost of PV system})/(\text{energy produced in 1 year})] + \text{Operating and maintenance}$

$$COE = \frac{(c_m + c_b)}{S\eta} F + OM$$

- where
- c_m is the PV module cost (in \$/m²)
- c_b is the BOS cost (in \$/m²)
- η is efficiency
- S is annual incident solar energy in kWhr/m²yr
- OM is operating and maintenance costs
- F is the cost associated with borrowing money

Cost of Electricity



Reducing Costs

- Improve BOS performance (without increasing costs)
 - Closer match between components, maximum power point tracking, etc
 - More efficient components
 - Improved storage
- Reduce BOS costs
 - Incorporate modules into rooftops
 - Improved inverter design, power conditioning,
- Improve module performance with optical concentration
 - Concentrators replace solar cells with cheaper optics
 - commercially may be difficult to implement due to tracking, increased temperature, alignment, reduced utilisation of indirect light and optical losses in system
 - Low scale concentration (4-20X) can use conventional cells designs, while high concentration suited primarily to large scale utility use and require high efficiency “laboratory” type cells

Reducing Costs

- Reduce solar cell substrate material cost
 - Silicon wafer costs are roughly 30-40% of total cell cost, therefore use thin-film concept
 - Reduce wafer thickness on crystalline solar cells (requires new design, especially rear surface)
 - Increase wafer diameter (more watts per piece)
 - Increase ingot length and reduce kerf losses in ingot sawing (more wafers per pull)
 - Reduce silicon feedstock cost
- Increase cell efficiency with novel solar cell designs
 - Bifacial technologies
 - Advanced screen printing techniques
- Lower cost technologies

Reducing Costs

- Reduce processing/materials costs through process engineering resulting in reduced material/processing costs
 - increased throughput, increased yield
 - novel processes, materials and concepts
 - increased wafer area
- Other financing schemes for PV
 - Present costing studies assume that the system is financed. Because of the large initial costs involved in a PV system, this can have a significant impact of the COE for a PV system.
- Economies of scale