# Environmental Economics

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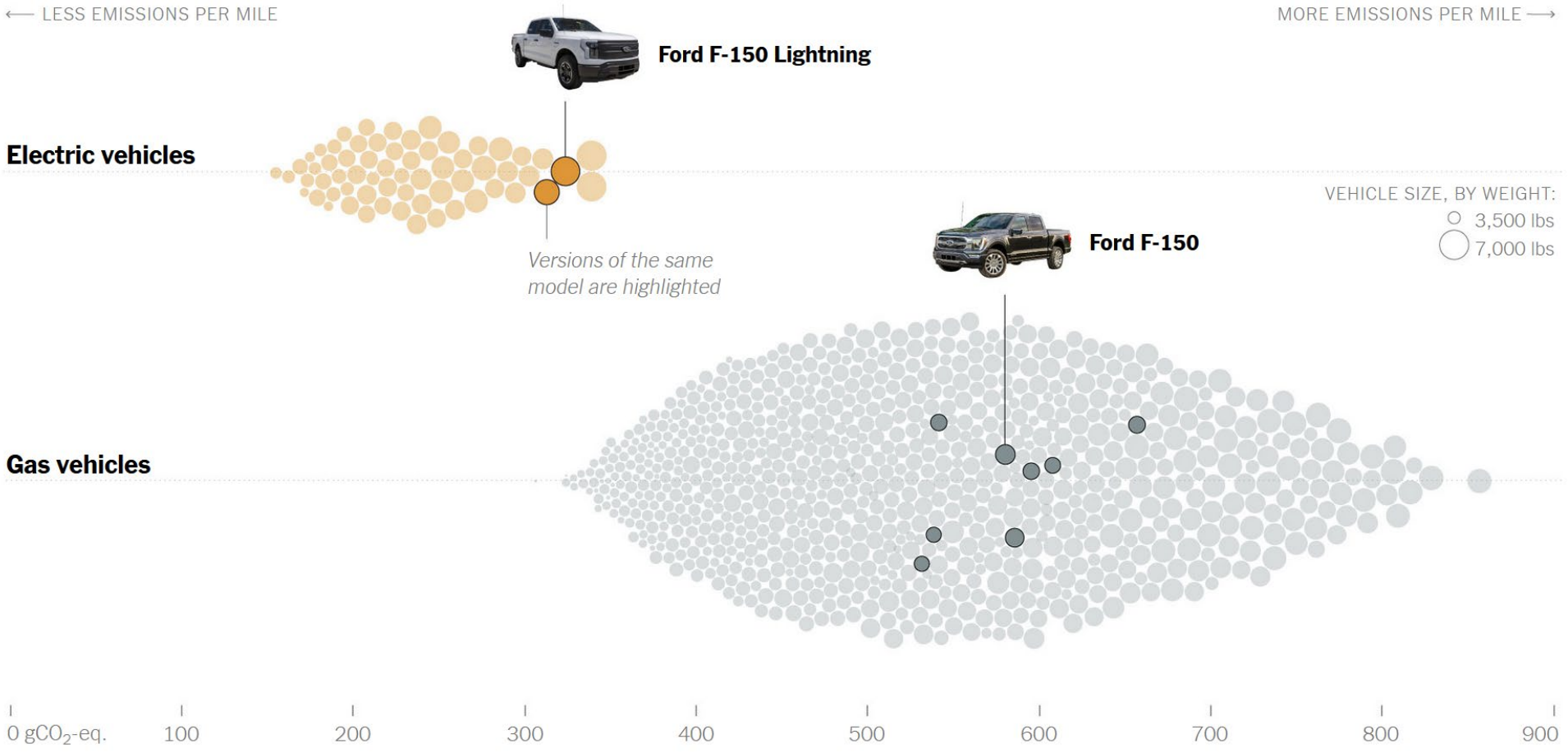
EPFL ENAC LEUrE

ENV-471

Master semester 2 or 4

# COMPARING OPTIONS THAT INVOLVE INTERTEMPORAL PAYMENTS

# EV vs ICE comparison on cradle-to-grave greenhouse gas emissions




Only the heaviest electric SUVs and pickups are ‘worse’ than the lightest ICE ('gas') cars

New York Times, "Just How Good for the Planet Is That Big Electric Pickup Truck?", 18 Feb. 2023

Source of data: carboncounter.com by the MIT Trancik Lab. Greenhouse gas emissions account for the entire life cycle of the vehicle, including vehicle and battery manufacturing, supply chain of raw materials, gas consumption, and electricity generation. Emissions from electricity generation reflect the average values from grids across the U.S.

# Comparing the costs of a BE and an ICE car*



| Cost factors | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend |
|---|---|---|
| **One-off costs** | | |
| Purchase price | 33 300 € | 24 550 € |
| Charging infrastructure | 1 100 € | 0 € |
| Subsidy / purchase premium | 4 000 € | 0 € |
| **Recurring costs (per year)** | | |
| Energy costs | 662 € | 1 170 € |
| Car ownership tax | 0 € | 98 € |
| Insurance | 969 € | 1 260 € |
| Maintenance / servicing | 552 € | 744 € |
| **Residual value** | | |
| Resale price after 5 years | 7 100 € | 6 070 € |

https://www.mobilityhouse.com/int_en/knowledge-center/cost-comparison-electric-car-vs-petrol-which-car-costs-more-annually
Consulted on 8 May 2023, data for Germany in 2021, subsidy corrected

What is the total cost of ownership (TCO) of each car?

*
BE = battery electric
ICE = internal combustion engine

# Method 1: sum of costs

| Cost factors | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend |
|---|---|---|
| **One-off costs** | | |
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| Energy costs | 662 € | 1 170 € |
| Car ownership tax | 0 € | 98 € |
| Insurance | 969 € | 1 260 € |
| Maintenance / servicing | 552 € | 744 € |
| **Residual value** | | |
| Resale price after 5 years | 7 100 € | 6 070 € |

| | | |
|---|---|---|
| Net acquisition cost | 30 400 € | 24 550 € |
| 5 years of annual costs | 10 915 € | 16 360 € |
| Residual value | -7 100 € | -6 070 € |
| **Total costs** | **34 215 €** | **34 840 €** |

Discuss:

- Need for public support: why? how much?
- Form of public support: what support is provided? alternative forms? advantages and drawbacks?
- No discounting

# Method 2: present value of costs

| Cost factors | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend |
|---|---|---|
| **One-off costs** | | |
| Purchase price | 33 300 € | 24 550 € |
| Charging infrastructure | 1 100 € | 0 € |
| Subsidy / purchase premium | 4 000 € | 0 € |
| **Recurring costs (per year)** | | |
| Energy costs | 662 € | 1 170 € |
| Car ownership tax | 0 € | 98 € |
| Insurance | 969 € | 1 260 € |
| Maintenance / servicing | 552 € | 744 € |
| **Residual value** | | |
| Resale price after 5 years | 7 100 € | 6 070 € |

$$\text{Discount factor} = (1+i)^{-\text{Discount years}}$$

| | | | Discount rate: | 4.0% | Discounted costs | |
|---|---|---|---|---|---|---|
| | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend | Discount years | Discount factor | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend |
| Start year 1 | 30 400 € | 24 550 € | 0 | 1.00 | 30 400 € | 24 550 € |
| Costs year 1 | 2 183 € | 3 272 € | 0.5 | 0.98 | 2 141 € | 3 208 € |
| Costs year 2 | 2 183 € | 3 272 € | 1.5 | 0.94 | 2 058 € | 3 085 € |
| Costs year 3 | 2 183 € | 3 272 € | 2.5 | 0.91 | 1 979 € | 2 966 € |
| Costs year 4 | 2 183 € | 3 272 € | 3.5 | 0.87 | 1 903 € | 2 852 € |
| Costs year 5 | 2 183 € | 3 272 € | 4.5 | 0.84 | 1 830 € | 2 743 € |
| End year 5 | -7 100 € | -6 070 € | 5 | 0.82 | -5 836 € | -4 989 € |
| | | | | **Total costs at start of year 1** | **34 475 €** | **34 416 €** |

# Sensitivity analysis

- Given the uncertainty relative to some key parameters, it is desirable to test the robustness of the main results (here, the ranking of the alternatives) to changes in these key parameters
- Here we test the sensitivity to the discount rate and the resale price premium of the BE car

| | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend |
|---|---|---|
| Discount rate = 0% | 34 215 € | 34 840 € |
| Discount rate = 4% | 34 475 € | 34 416 € |
| Discount rate = 8% | 34 626 € | 33 996 € |
| Resale price premium = 515 | 34 898 € | 34 416 € |
| Resale price premium = 1030 | 34 475 € | 34 416 € |
| Resale price premium = 2060 | 33 629 € | 34 416 € |

- A higher discount rate makes the BE car relatively more expensive, because the later cost savings and resale price premium are less valuable
- A somewhat higher resale price premium would make the BE car cheaper than the ICE car

# Method 3: average annual cost

- The one-off costs and resale price are divided by the number of years of operation (5 years)
- Beware of the signs!

| | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend |
|---|---|---|
| **One-off costs** | | |
| Purchase price | 6 660 € | 4 910 € |
| Charging infrastructure | 220 € | 0 € |
| Subsidy / purchase premium | - 800 € | 0 € |
| **Recurring costs (per year)** | | |
| Energy costs | 662 € | 1 170 € |
| Car ownership tax | 0 € | 98 € |
| Insurance | 969 € | 1 260 € |
| Maintenance / servicing | 552 € | 744 € |
| **Residual value** | | |
| Resale price after 5 years | -1 420 € | -1 214 € |
| **Total yearly costs** | **6 843 €** | **6 968 €** |

'Total yearly costs' is equal to the simple sum of costs divided by the number of years of operation

# Method 4: average annual costs with discounting

- The challenge is to convert a one-off cost into a stream of constant annual costs whose present value is equal
- In finance, this is known as an 'annuity' calculation
- This is the general formula:

$$\mathrm{PV}(A;i;n)=\sum_{t=1}^{n}\frac{A}{(1+i)^t}=\frac{A}{i}\times\frac{(1+i)^n-1}{(1+i)^n}=C$$

$$A=C\times\frac{i\times(1+i)^n}{(1+i)^n-1}$$

- The fraction multiplying C is called the **capital recovery factor** (CRF)
- One-off costs or revenues that occur after 'date 0' must first be discounted to 'date 0'
- E.g., for the resale price $P_n$ in year n: $A=\frac{P_n}{(1+i)^n}\times\frac{i\times(1+i)^n}{(1+i)^n-1}=P_n\times\frac{i}{(1+i)^n-1}$

# Method 4: average annual costs with discounting

| | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend |
|---|---|---|
| Net acquisition cost | 30 400 € | 24 550 € |
| Annuity of acquisition cost | 6 829 € | 5 515 € |
| Resale price after 5 years | 7 100 € | 6 070 € |
| PV of resale price | 5 836 € | 4 989 € |
| Annuity of resale price | 1 311 € | 1 121 € |

| | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend |
|---|---|---|
| **One-off costs** | | |
| Annuity of acquisition cost | 6 829 € | 5 515 € |
| **Recurring costs (per year)** | | |
| Energy costs | 662 € | 1 170 € |
| Car ownership tax | 0 € | 98 € |
| Insurance | 969 € | 1 260 € |
| Maintenance / servicing | 552 € | 744 € |
| **Residual value** | | |
| Annuity of resale price | -1 311 € | -1 121 € |
| **Total yearly costs** | **7 701 €** | **7 666 €** |

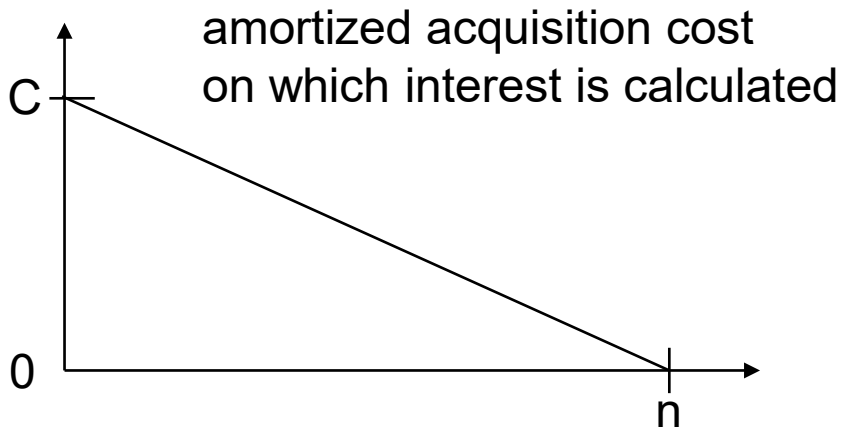
The annuity of 6 829 € compares with acquisition cost / 5 = 6 080 €

The annuity of 1 311 € compares with resale price / 5 = 1 420 €

With discounting, the annual costs are higher, because there is an interest cost counted in the acquisition cost

# Method 5: simplified calculation of interest cost

- The annuity is made of two components: (1) 'amortization' of the initial investment and (2) interest on outstanding (= not yet amortized) investment
- Amortization = C/n
- Interest is due on the surface of the triangle below = C×n/2 → C×i/2 per year




- Simplified annuity = C/n + C×i/2
- For the acquisition cost of the BE car, simplified annuity = 6 688 €, to be compared with exact annuity = 6 829 € and with C/5 = 6 080 €

# Method 5: average annual costs with simplified annuity calculation

| | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend |
|---|---|---|
| **One-off costs** | | |
| Simplified annuity of acquisition cost minus resale price | 5 126 € | 744 € |
| **Recurring costs (per year)** | | |
| Energy costs | 662 € | 1 170 € |
| Car ownership tax | 0 € | 98 € |
| Insurance | 969 € | 1 260 € |
| Maintenance / servicing | 552 € | 744 € |
| **Total yearly costs** | **7 309 €** | **4 016 €** |

'C' in the simplified annuity calculation C/n + C×i/2 is net acquisition cost minus resale price: this is the amount to be amortized and interest paid on

- For the BE car, TCO with simplified annuity calculation = 7 309 €, to be compared with TCO with exact annuity = 7 701 € and with TCO based on simple average = 6 843 €

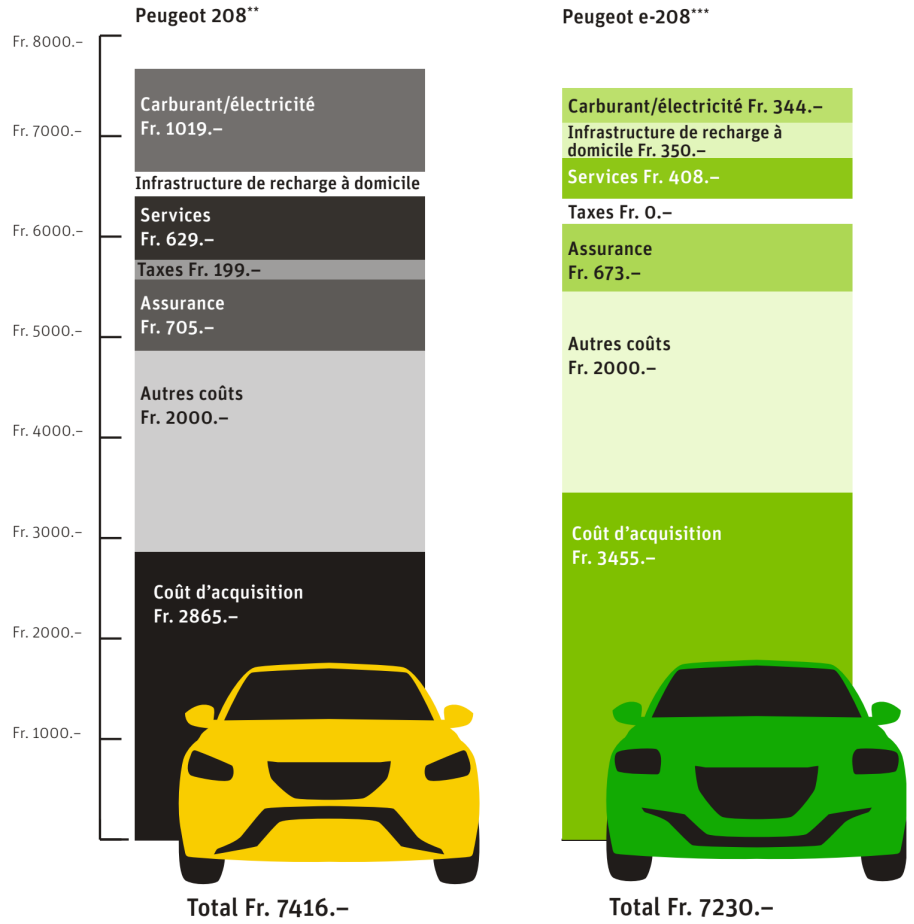
# Cost comparisons in practice

## Sum of costs (undiscounted)

| Cost factors | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend DCT |
|---|---|---|
| **One-off costs** | | |
| Purchase price | 33.300 € | 24.550 € |
| Charging infrastructure | 1.100 € | 0 € |
| Subsidy / purchase premium | -9.000 € | 0 € |
| **Recurring costs (per year)** | | |
| Consumption costs | 662 € | 1.170 € |
| Car tax | 0 € | 98 € |
| Insurance | 969 € | 1.260 € |
| Maintenance / servicing | 552 € | 744 € |
| Residual value | 7.100 € | 6.070 € |
| **Total costs** | **34.213 €** | **34.840 €** |

The Mobility House, copied on 8.5.23, subsidy mistaken, https://www.mobilityhouse.com/int_en/knowledge-center/cost-comparison-electric-car-vs-petrol-which-car-costs-more-annually

## Mean annual costs (undiscounted)

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# INVESTMENT DECISION

# Investing into the costlier option

- Buying the more expensive BE car rather than the ICE can be interpreted as an investment, with returns in the form of lower running costs and a higher residual value

| | Hyundai IONIQ Elektro Trend | Hyundai i30 1.4 T-GDI Trend | ICE - BE |
|---|---|---|---|
| Net acquisition cost | 30 400 € | 24 550 € | -5 850 € |
| Running costs year 1 | 2 183 € | 3 272 € | 1 089 € |
| Running costs year 2 | 2 183 € | 3 272 € | 1 089 € |
| Running costs year 3 | 2 183 € | 3 272 € | 1 089 € |
| Running costs year 4 | 2 183 € | 3 272 € | 1 089 € |
| Running costs year 5 | 2 183 € | 3 272 € | 1 089 € |
| Residual value | -7 100 € | -6 070 € | 1 030 € |

- Is this a profitable investment?

# Net value and net present value (NPV)

- The investment is profitable if incomes (here: cost savings and resale premium) exceed the investment
- Proper calculation discounts all payments to the same date
- Investing into BE is not profitable with 4% discount rate

| | ICE - BE |
|---|---|
| Net acquisition cost | -5 850 € |
| Running costs year 1 | 1 089 € |
| Running costs year 2 | 1 089 € |
| Running costs year 3 | 1 089 € |
| Running costs year 4 | 1 089 € |
| Running costs year 5 | 1 089 € |
| Residual value | 1 030 € |
| **Net value (no discounting)** | **625 €** |

| | | | Discount rate: | 4.0% | |
|---|---|---|---|---|---|
| | **ICE - BE** | | Discount years | Discount factor | **Present value** |
| Net acquisition cost | -5 850 € | | 0 | 1.00 | -5 850 € |
| Running costs year 1 | 1 089 € | | 0.5 | 0.98 | 1 068 € |
| Running costs year 2 | 1 089 € | | 1.5 | 0.94 | 1 027 € |
| Running costs year 3 | 1 089 € | | 2.5 | 0.91 | 987 € |
| Running costs year 4 | 1 089 € | | 3.5 | 0.87 | 949 € |
| Running costs year 5 | 1 089 € | | 4.5 | 0.84 | 913 € |
| Residual value | 1 030 € | | 5 | 0.82 | 847 € |
| **NET PRESENT VALUE** | | | | | **- 59 €** |

# Net Present Value (NPV)

- Definition
  - The NPV is the sum of discounted payments (incomes or benefits minus costs and other outlays) over the period

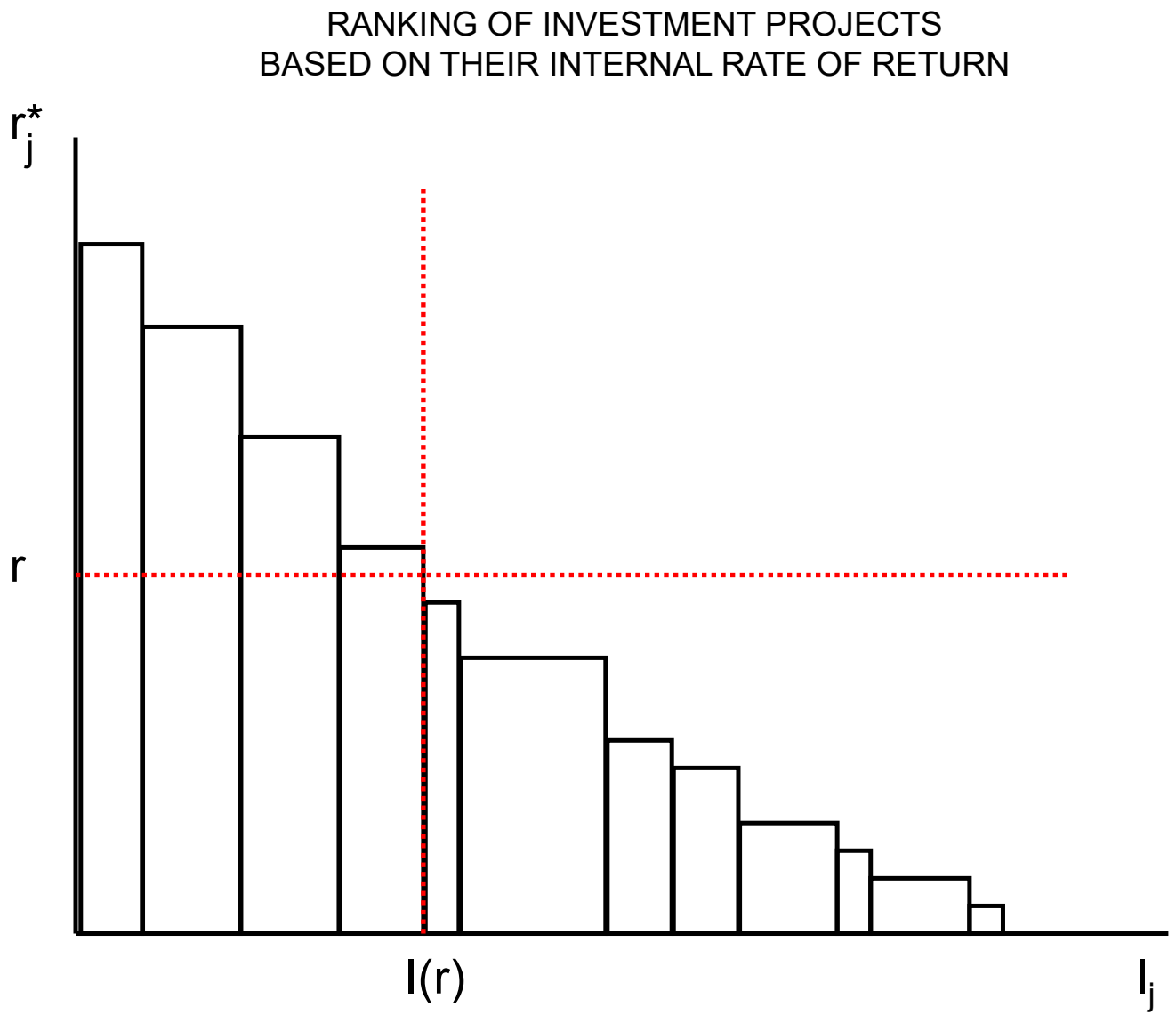
$$NPV = (B-C)_0 + \frac{(B-C)_1}{(1+i)^1} + \frac{(B-C)_2}{(1+i)^2} + \ldots + \frac{(B-C)_n}{(1+i)^n} = \sum_{t=0}^{n} \frac{(B-C)_t}{(1+i)^t} = \sum_{t=0}^{n} f_t (B-C)_t$$

- Decision rule
  - For unique project: approve the project if $NPV \geq 0$
  - For competing projects requiring investments of similar magnitude: select the project with the highest NPV, if its $NPV \geq 0$
- Advantages: simple use, easy selection of rival projects (if all C&B included)
- Disadvantages: need to select discount rate *i*

# Internal rate of return (IRR)

- Investing in the more expensive BE car is profitable at 0% discount rate but not at 4% discount rate
- There must be a discount rate at which the investment just breaks even (NPV = 0)
- This is the **internal rate of return**
- It can be found by trial and error (vary discount rate until NPV = 0) or with the IRR function of the calculation tool
- For the BE over ICE 'investment', IRR = 3.62%
- Is this enough? Set a **'hurdle rate'**, which can then serve as discount rate!

# Hurdle rate




- The **hurdle rate** is the required rate of return for this type of investment
- I(r) is the amount that can be invested with (expected) IRR greater than hurdle rate r
- Anything that lowers the hurdle rate or raises the IRR of projects triggers more investment

# Internal Rate of Return (IRR)

- Alternative method which is useful for proposals for which it is very difficult to determine a suitable discount rate *i*
- Definition: The IRR is the discount rate *r* which would give an NPV of zero, given expected benefits and costs

$$0 = (B-C)_0 + \frac{(B-C)_1}{(1+r)^1} + \frac{(B-C)_2}{(1+r)^2} + \ldots + \frac{(B-C)_n}{(1+r)^n} = \sum_{t=0}^{n} \frac{(B-C)_t}{(1+r)^t}$$

- Decision rule for competing proposals: pick the project with the highest IRR, if IRR $\geq 0$
- Advantage: no need to choose a discount rate
- Disadvantage: the size of the project is not considered; a small project with a NPV of CHF1,000 and an IRR of 25% would be preferred to a large project with a NPV of CHF1,000,000 and an IRR of 20%

# Benefit-Cost Ratio (BC ratio)

- Definition :
  - The BC ratio is the ratio between discounted benefits and discounted costs over the period of *n* years, given the discount rate *i*
  - BC ratio >1 implies NPV > 0

$$\text{BC ratio} = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}}$$

- Decision rule :
  - Unique project: approve the project if BC ratio $\geq 1$
  - For competing proposals: picking the projects with the highest BC ratio, provided BC ratio $\geq 1$
- Advantage/disadvantage: equivalent to NPV

# Benefit-Cost Ratio

| | | Discount rate: | 4.0% | |
|---|---|---|---|---|
| | **ICE - BE** | Discount years | Discount factor | **Present value** |
| Net acquisition cost | -5 850 € | 0 | 1.00 | -5 850 € |
| Running costs year 1 | 1 089 € | 0.5 | 0.98 | 1 068 € |
| Running costs year 2 | 1 089 € | 1.5 | 0.94 | 1 027 € |
| Running costs year 3 | 1 089 € | 2.5 | 0.91 | 987 € |
| Running costs year 4 | 1 089 € | 3.5 | 0.87 | 949 € |
| Running costs year 5 | 1 089 € | 4.5 | 0.84 | 913 € |
| Residual value | 1 030 € | 5 | 0.82 | 847 € |
| **NET PRESENT VALUE** | | | | **- 59 €** |

Discount factor = $(1+i)^{-\text{Discount years}}$

| | |
|---|---|
| PV of costs | 5 850 € |
| PV of benefits | 5 791 € |
| B/C ratio | 0.99 € |

- Investors sometimes want to compare total benefits to total costs
- Netting out creates some confusion between costs and benefits

# Payback period

- Definition: number of years until the benefits exceed the initial cost
- Very popular in the private sector
- It is a measure of time, not a measure of value
- To illustrate with BE vs ICE example, the fixed holding period and the residual value must be abandoned, unless there is a physical or legal end-of-life

# Payback period for BE car

| | | | Discount rate: 4.0% | | | |
|---|---|---|---|---|---|---|
| | **ICE - BE** | Sum of payments | Discount years | Discount factor | Present value | **NPV** |
| Net acquisition cost | -5 850 € | -5 850 € | 0 | 1.00 | -5 850 € | -5 850 € |
| Running costs year 1 | 1 089 € | -4 761 € | 0.5 | 0.98 | 1 068 € | -4 782 € |
| Running costs year 2 | 1 089 € | -3 672 € | 1.5 | 0.94 | 1 027 € | -3 755 € |
| Running costs year 3 | 1 089 € | -2 583 € | 2.5 | 0.91 | 987 € | -2 768 € |
| Running costs year 4 | 1 089 € | -1 494 € | 3.5 | 0.87 | 949 € | -1 819 € |
| Running costs year 5 | 1 089 € | - 405 € | 4.5 | 0.84 | 913 € | - 906 € |
| Running costs year 6 | 1 089 € | **684 €** | 5.5 | 0.81 | 878 € | - 28 € |
| Running costs year 7 | 1 089 € | 1 773 € | 6.5 | 0.77 | 844 € | **816 €** |
| Running costs year 8 | 1 089 € | 2 862 € | 7.5 | 0.75 | 811 € | 1 627 € |

- The NPV in the last column is the present value of all 'payments' up to that year
- The NPV turns positive with year 7, i.e., the BE is the better choice for a user who plans to use her car for 7 years at least
- Without discounting, payback period = 6 years

# Levelized cost of electricity and payback period for a CCGT plant in UK

| | | Project start | | Construction start | | | Operation start | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **2020** | 2021 | **2022** | 2023 | 2024 | **2025** | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 | 2044 | 2045 | 2046 | 2047 | 2048 | 2049 |
| Hurdle rate | | 7.5% | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Discount factor | | 100.0% | 93.0% | 86.5% | 80.5% | 74.9% | 69.7% | 64.8% | 60.3% | 56.1% | 52.2% | 48.5% | 45.1% | 42.0% | 39.1% | 36.3% | 33.8% | 31.4% | 29.2% | 27.2% | 25.3% | 23.5% | 21.9% | 20.4% | 18.9% | 17.6% | 16.4% | 15.3% | 14.2% | 13.2% | 12.3% |
| Development cost | £m | 5.2 | 6.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Construction cost | £m | | | 288.0 | 288.0 | 144.0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fixed O&M | £m | | | | | | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 | 24.2 |
| Variable O&M | £m | | | | | | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 | 19.6 |
| Fuel costs | £m | | | | | | 403.6 | 354.7 | 366.9 | 373.0 | 385.2 | 391.3 | 397.5 | 403.6 | 409.7 | 415.8 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 | 421.9 |
| Social cost of carbon | £m | | | | | | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 | 280.2 |
| TOTAL COST | £m | **5.2** | **6.8** | **288.0** | **288.0** | **144.0** | **727.5** | **678.6** | **690.8** | **697.0** | **709.2** | **715.3** | **721.4** | **727.5** | **733.7** | **739.8** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** | **745.9** |
| Discounted costs | £m | 5.2 | 6.4 | 249.2 | 231.8 | 107.8 | 506.8 | 439.7 | 416.4 | 390.8 | 369.9 | 347.1 | 325.6 | 305.5 | 286.5 | 268.8 | 252.1 | 234.5 | 218.1 | 202.9 | 188.8 | 175.6 | 163.3 | 151.9 | 141.3 | 131.5 | 122.3 | 113.8 | 105.8 | 98.5 | 91.6 |
| Power generation | GWh | | | | | | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 | 9 776 |
| Discounted power gen. | MWh | | | | | | 6 810 | 6 335 | 5 893 | 5 482 | 5 099 | 4 743 | 4 412 | 4 105 | 3 818 | 3 552 | 3 304 | 3 073 | 2 859 | 2 660 | 2 474 | 2 301 | 2 141 | 1 992 | 1 853 | 1 723 | 1 603 | 1 491 | 1 387 | 1 290 | 1 200 |
| Sum discounted costs | £m | 6 649 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sum disc. power gen. | GWh | 81 600 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| LCOE | £/MWh | **81.5** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Price of electricity | £/MWh | 81.5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Revenue from electr. | £m | | | | | | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 | 796.6 |
| Disc. revenue | £m | | | | | | 554.9 | 516.2 | 480.2 | 446.7 | 415.5 | 386.5 | 359.6 | 334.5 | 311.1 | 289.4 | 269.2 | 250.5 | 233.0 | 216.7 | 201.6 | 187.5 | 174.5 | 162.3 | 151.0 | 140.4 | 130.6 | 121.5 | 113.0 | 105.2 | 97.8 |
| Disc. revenue-costs | £m | -5.2 | -6.4 | -249.2 | -231.8 | -107.8 | 48.1 | 76.5 | 63.8 | 55.9 | 45.6 | 39.5 | 34.0 | 29.0 | 24.6 | 20.7 | 17.2 | 16.0 | 14.8 | 13.8 | 12.8 | 11.9 | 11.1 | 10.3 | 9.6 | 8.9 | 8.3 | 7.7 | 7.2 | 6.7 | 6.2 |
| NPV | £m | -5.2 | -11.5 | -260.7 | -492.6 | -600.4 | -552.3 | -475.8 | -412.0 | -356.1 | -310.5 | -271.0 | -237.1 | -208.1 | -183.5 | -162.8 | -145.6 | -129.7 | -114.8 | -101.0 | -88.2 | -76.2 | -65.1 | -54.8 | -45.2 | -36.2 | -27.9 | -20.1 | -12.9 | -6.2 | 0.0 |
| *Results for price = 82.5* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Disc. revenue-costs | £m | -5.2 | -6.4 | -249.2 | -231.8 | -107.8 | 55.0 | 82.9 | 69.7 | 61.4 | 50.8 | 44.3 | 38.4 | 33.2 | 28.5 | 24.3 | 20.5 | 19.1 | 17.7 | 16.5 | 15.3 | 14.3 | 13.3 | 12.4 | 11.5 | 10.7 | 9.9 | 9.3 | 8.6 | 8.0 | 7.4 |
| NPV | £m | -5.2 | -11.5 | -260.7 | -492.6 | -600.4 | -545.4 | -462.5 | -392.7 | -331.3 | -280.5 | -236.3 | -197.8 | -164.7 | -136.2 | -112.0 | -91.5 | -72.4 | -54.6 | -38.1 | -22.8 | -8.5 | 4.8 | 17.1 | 28.6 | 39.3 | 49.2 | 58.5 | 67.1 | 75.1 | 82.6 |
| *Results for price = 80.5* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Disc. revenue-costs | £m | -5.2 | -6.4 | -249.2 | -231.8 | -107.8 | 41.4 | 70.2 | 57.9 | 50.5 | 40.6 | 34.8 | 29.6 | 25.0 | 20.8 | 17.2 | 13.9 | 12.9 | 12.0 | 11.2 | 10.4 | 9.7 | 9.0 | 8.4 | 7.8 | 7.2 | 6.7 | 6.3 | 5.8 | 5.4 | 5.0 |
| NPV | £m | -5.2 | -11.5 | -260.7 | -492.6 | -600.4 | -559.0 | -488.8 | -430.8 | -380.3 | -339.8 | -305.0 | -275.4 | -250.4 | -229.6 | -212.4 | -198.6 | -185.6 | -173.6 | -162.4 | -152.0 | -142.4 | -133.4 | -125.0 | -117.2 | -110.0 | -103.2 | -96.9 | -91.1 | -85.7 | -80.6 |

Data from https://www.gov.uk/government/publications/electricity-generation-costs-2023, Annex B <02.05.2024>

# A particular type of payback period: energy or $CO_2$ recovery

- Many measures serving to reduce energy consumption or $CO_2$ emissions involve new equipment and/or construction work (e.g. replacing machines, insulating buildings)
- These measures cause energy use and $CO_2$ emissions → 'embodied energy or $CO_2$', 'grey energy or $CO_2$'
- Spending energy to save energy, emitting $CO_2$ to reduce $CO_2$ emissions…
- This only makes sense if the energy savings thus obtained exceed embodied energy, and the $CO_2$ emissions avoided exceed embodied $CO_2$
- How many years of these savings are needed to offset the embodied pollution?
- Example: typical energy refurbishment of buildings 'costs' 440 $kgCO_2/m^2$, which corresponds to 10 years of thus avoided $CO_2$ emissions

# EXAMPLE – PV ON YOUR ROOF

# Illustrative data for PV on single-family houses in Switzerland (early 2022)

| | Costs and benefits (CHF) |
|---|---|
| One-off costs | |
| Investment cost | 30 000 |
| Subsidy | 4 500 |
| Tax rebate | 5 000 |
| Annual benefits and costs | |
| Electricity saving | 600 |
| Revenue from electricity sales | 630 |
| Maintenance | 180 |

Assumption: 25% self-consumption
Typical life expectancy: 25 years

# Cleaning up costs and incomes

| | Costs and benefits (CHF) |
|---|---|
| One-off costs | |
| Investment cost | 30 000 |
| Subsidy | 4 500 |
| Tax rebate | 5 000 |
| Annual benefits and costs | |
| Electricity saving | 600 |
| Revenue from electricity sales | 630 |
| Maintenance | 180 |

| | |
|---|---|
| Initial investment | -20 500 |
| Yearly net income | 1 050 |

- Direct rate of return: 1050 / 20 500 = 5.1%
- What is the problem with this number?

# NPV

| discount rate: | | 0.0% | | |
|---|---|---|---|---|
| | Payments | Discount years | Discount factor | Discounted payments |
| Initial investment | -20 500 | 0 | 1.00 | -20 500 |
| Income year 1 | 1 050 | 1 | 1.00 | 1 050 |
| Income year 2 | 1 050 | 2 | 1.00 | 1 050 |
| Income year 3 | 1 050 | 3 | 1.00 | 1 050 |
| Income year 4 | 1 050 | 4 | 1.00 | 1 050 |
| Income year 5 | 1 050 | 5 | 1.00 | 1 050 |
| Income year 6 | 1 050 | 6 | 1.00 | 1 050 |
| Income year 7 | 1 050 | 7 | 1.00 | 1 050 |
| Income year 8 | 1 050 | 8 | 1.00 | 1 050 |
| Income year 9 | 1 050 | 9 | 1.00 | 1 050 |
| Income year 10 | 1 050 | 10 | 1.00 | 1 050 |
| Income year 11 | 1 050 | 11 | 1.00 | 1 050 |
| Income year 12 | 1 050 | 12 | 1.00 | 1 050 |
| Income year 13 | 1 050 | 13 | 1.00 | 1 050 |
| Income year 14 | 1 050 | 14 | 1.00 | 1 050 |
| Income year 15 | 1 050 | 15 | 1.00 | 1 050 |
| Income year 16 | 1 050 | 16 | 1.00 | 1 050 |
| Income year 17 | 1 050 | 17 | 1.00 | 1 050 |
| Income year 18 | 1 050 | 18 | 1.00 | 1 050 |
| Income year 19 | 1 050 | 19 | 1.00 | 1 050 |
| Income year 20 | 1 050 | 20 | 1.00 | 1 050 |
| Income year 21 | 1 050 | 21 | 1.00 | 1 050 |
| Income year 22 | 1 050 | 22 | 1.00 | 1 050 |
| Income year 23 | 1 050 | 23 | 1.00 | 1 050 |
| Income year 24 | 1 050 | 24 | 1.00 | 1 050 |
| Income year 25 | 1 050 | 25 | 1.00 | 1 050 |
| | | | **NPV** | **5 750** |

| discount rate: | | 4.0% | | |
|---|---|---|---|---|
| | Payments | Discount years | Discount factor | Discounted payments |
| Initial investment | -20 500 | 0 | 1.00 | -20 500 |
| Income year 1 | 1 050 | 1 | 0.96 | 1 010 |
| Income year 2 | 1 050 | 2 | 0.92 | 971 |
| Income year 3 | 1 050 | 3 | 0.89 | 933 |
| Income year 4 | 1 050 | 4 | 0.85 | 898 |
| Income year 5 | 1 050 | 5 | 0.82 | 863 |
| Income year 6 | 1 050 | 6 | 0.79 | 830 |
| Income year 7 | 1 050 | 7 | 0.76 | 798 |
| Income year 8 | 1 050 | 8 | 0.73 | 767 |
| Income year 9 | 1 050 | 9 | 0.70 | 738 |
| Income year 10 | 1 050 | 10 | 0.68 | 709 |
| Income year 11 | 1 050 | 11 | 0.65 | 682 |
| Income year 12 | 1 050 | 12 | 0.62 | 656 |
| Income year 13 | 1 050 | 13 | 0.60 | 631 |
| Income year 14 | 1 050 | 14 | 0.58 | 606 |
| Income year 15 | 1 050 | 15 | 0.56 | 583 |
| Income year 16 | 1 050 | 16 | 0.53 | 561 |
| Income year 17 | 1 050 | 17 | 0.51 | 539 |
| Income year 18 | 1 050 | 18 | 0.49 | 518 |
| Income year 19 | 1 050 | 19 | 0.47 | 498 |
| Income year 20 | 1 050 | 20 | 0.46 | 479 |
| Income year 21 | 1 050 | 21 | 0.44 | 461 |
| Income year 22 | 1 050 | 22 | 0.42 | 443 |
| Income year 23 | 1 050 | 23 | 0.41 | 426 |
| Income year 24 | 1 050 | 24 | 0.39 | 410 |
| Income year 25 | 1 050 | 25 | 0.38 | 394 |
| | | | **NPV** | **-4 097** |

# NPV

- At 0% discount rate, the NPV is positive over 25 years
- At 4% discount rate, the NPV is negative over 25 years
- IRR = 2.0%
- Payback period without discounting < 25 years
- Payback period with 4% discounting > 25 years
- Payback period with 2% discounting = 25 years

# Payback period with discounting

- NPV only turns positive with 39 years of incomes
- How patient is an investor discounting at 4%?
- Is it reasonable to assume constant income?
- Relationship between discount rate and evolution of incomes…

| | discount rate: | 4.0% | | | |
|---|---|---|---|---|---|
| | Payments | Discount years | Discount factor | Discounted payments | NPV |
| Initial investment | -20 500 | 0 | 1.00 | -20 500 | -20 500 |
| Income year 1 | 1 050 | 1 | 0.96 | 1 010 | -19 490 |
| Income year 2 | 1 050 | 2 | 0.92 | 971 | -18 520 |
| Income year 3 | 1 050 | 3 | 0.89 | 933 | -17 586 |
| Income year 4 | 1 050 | 4 | 0.85 | 898 | -16 689 |
| Income year 5 | 1 050 | 5 | 0.82 | 863 | -15 826 |
| Income year 6 | 1 050 | 6 | 0.79 | 830 | -14 996 |
| Income year 7 | 1 050 | 7 | 0.76 | 798 | -14 198 |
| Income year 8 | 1 050 | 8 | 0.73 | 767 | -13 431 |
| Income year 9 | 1 050 | 9 | 0.70 | 738 | -12 693 |
| Income year 10 | 1 050 | 10 | 0.68 | 709 | -11 984 |
| Income year 31 | 1 050 | 31 | 0.30 | 311 | -2 032 |
| Income year 32 | 1 050 | 32 | 0.29 | 299 | -1 733 |
| Income year 33 | 1 050 | 33 | 0.27 | 288 | -1 445 |
| Income year 34 | 1 050 | 34 | 0.26 | 277 | -1 168 |
| Income year 35 | 1 050 | 35 | 0.25 | 266 | - 902 |
| Income year 36 | 1 050 | 36 | 0.24 | 256 | - 646 |
| Income year 37 | 1 050 | 37 | 0.23 | 246 | - 400 |
| Income year 38 | 1 050 | 38 | 0.23 | 237 | - 164 |
| Income year 39 | 1 050 | 39 | 0.22 | 227 | 64 |
| Income year 40 | 1 050 | 40 | 0.21 | 219 | 282 |

# DISCUSSION

# Which decision rule to adopt?

- NPV, benefit-cost ratio, IRR or payback period?
- What discount rate or hurdle rate?
- What horizon?
- How to handle risk?
- What importance for this financial calculation?
- Other criteria (liquidity constraint)?
- Influence of personal characteristics and practices on 'profitability'
- Multiple objectives