Ecolnomic feasibility of cross-section of the pressure tunnel and penstock

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Autumn semester 2021-2022 | Hydroelectric power

Methodology

The objective of this exercise is to optimise the geometry of the headrace (pressure) tunnel and the penstock. In this step of the design process we need to consider construction criteria and financial feasability. Our analysis is based on the following table :

Diameter	Hydraulic loss coefficient	Construction costs	Energy loss	Loss of energy	Cost of the lost energy
[m]	/	[€]	[m]	[kW.h]	[€]

Diameter
This is our variable, we will calculate very other parameters based on its variation.
For the tunnel, the diameter varies as : [4 | 4,5 | 5 | 5,5 | 6]. And for the penstock : [4 | 4,5 | 5 | 5,5].

Hydraulic loss coefficient

To calculate those coefficient we will be using the same methods than the first exercise. I'm once again using python for calculations. The code is available at the end of this document.

Construction costs

- Pressure tunnel construction cost breakdown :
  - 2% for the preparation of works,
  - 16,5% for the earthworks,
  - 22% for jet grounding,
  - 22% for support,
  - 36% for the concrete works.
- Penstock construction breakdown :
  - 2% for earthworks and preparation,
  - 2% for concrete works,
  - 20% for hydraulic equipement,
  - 76% for steel pipeline.

To calculate the global cost of all of this construction operation we use the following formula (where D is the diamater.) :

$$Costs = 1435,36.D - 615,646$$

Energy loss
As we calculate the hydraulic loss cofficient, we have $\Delta h = K.Q^2$ where K is the hydraulic coefficient and Q the flow rate.

Loss of energy in kW.h

Or calculation of the lost energy is estimated based on :

- the design ccaracteristic of the trubine,
- the flow duration curve,
- all the hydraulic losses.

<u>For energy production in one year :</u>

$$E = \eta_{ag}.9,81.H_{net}.Q_{med}.\eta_i.T$$

Where :

- η_{ag} is the utilisation coefficient for the entire power unit (turbine, transformer, generator and switch)

  $\eta_{ag} = \eta_{tur}.\eta_{trans}.\eta_{gen}.\eta_{sw} = 0,865$
- $H_{net} = H - \Delta h$
- $Q_{med} = 16,6\ m^3.s^{-1}$, the discharge estimated with a hydrological study
- $\eta_i = 0,9$, the utilisation rate of the yearly inflow from the flow duration curve
- $T = 2600$, the numbers of hours in a year

Cost of the loss energy

We can calculate : $\Delta C = \Delta E.c$, where $c = 0,07$ €/kW.h

Input data

For each case fo diameter we got this table for input data :

TUNNEL		
Construction time		
D	4	*m*
Lost	595,936394	*EUR/m*
Investment	5125,794	*EUR/m*
Operational costst	51,25794	*Eur/year*
Income	3075,4764	*Eur/year*
Discount rate	5,00%	*%*
Reference period	20	*years*
Construction time	4	*years*

- Lost: corresponds to cost of lost energy
- Investment: corresponds to the construction costs
- Operational costst: yearly operation and maintenance expenses represent 1% of initial investment
- Income: yearly income represent 60% of initial investment
- Discount rate: discount rate helps us account for the time value of money
- Construction time: construction of the powerhouse will last 4 years

Financial items

We can now make this next table that give us a report about the cost and income for the 4 years of construction and the next 20 years of operation :

The investment is only made during the production period, which corresponds to the first four years.

Operational costs start as soon as the construction is finished

Financial items					
Investment	Operational costs	Income	Lost production	Year	Operational year
1281,4485	0	0	0	1	
1281,4485	0	0	0	2	
1281,4485	0	0	0	3	
1281,4485	0	0	0	4	
0	51,25794	0	595,936394	5	1
0	51,25794	0	595,936394	6	2
0	51,25794	0	595,936394	7	3
0	51,25794	0	595,936394	8	4
0	51,25794	0	595,936394	9	5
0	51,25794	0	595,936394	10	6
0	51,25794	0	595,936394	11	7
0	51,25794	0	595,936394	12	8
0	51,25794	0	595,936394	13	9
0	51,25794	0	595,936394	14	10
0	51,25794	0	595,936394	15	11
0	51,25794	0	595,936394	16	12
0	51,25794	0	595,936394	17	13
0	51,25794	0	595,936394	18	14
0	51,25794	0	595,936394	19	15
0	51,25794	0	595,936394	20	16
0	51,25794	0	595,936394	21	17
0	51,25794	0	595,936394	22	18
0	51,25794	0	595,936394	23	19
0	51,25794	3075,4764	595,936394	24	20

the first income arrives from the twentieth year of operation

There is a loss of production as soon as the dam is operational

Net present value

Net present value is calculated as the difference of present value of benefits and present value of expenditure. This calculus is done over the lifetim of a project. This value is used to understand the risk an investor is taking. It is a good indicator for comparing the economic viability of different projects.

Generally speaking :

- If $NPV > 0$, the project can be accepted
- if $NPV < 0$, the project is rejected

We can, therefore, calculate an NPV with the following formula :

$$NPV(i,n) = \sum_{i=0}^{n} \frac{CF_i}{(1+r)^i}$$

Where r is the discount value and CF_i the balanc of cash flow.

We have the following table :

NPV:			
Outcome: Investment	4 543,95 €	*EUR*	NPV of the investment column (1)
Outcome: Operation	525,53 €	*EUR*	NPV of the operational cost column (2)
Income	953,61 €	*EUR*	NPV of the income column (3)
Lost production	6 109,95 €	*EUR*	NPV of the lost production column (4)
Sum of the outcome	5 069,48 €	*EUR*	(1)+(2)
Nt outcome(out-in)	4 115,88 €	*EUR*	(1)+(2)-(3)=(5)
NPV sum (net out+lost prod)	10 225,83 €	*EUR*	(5)-(4)

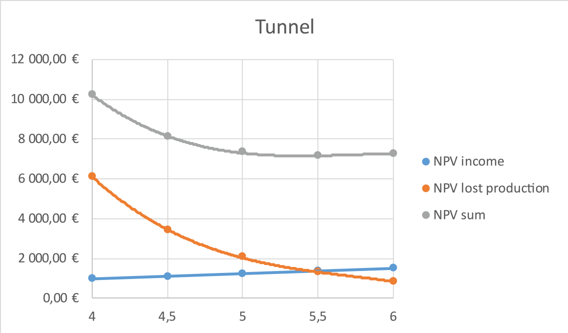
Compilation of calculations and diameter optimisation

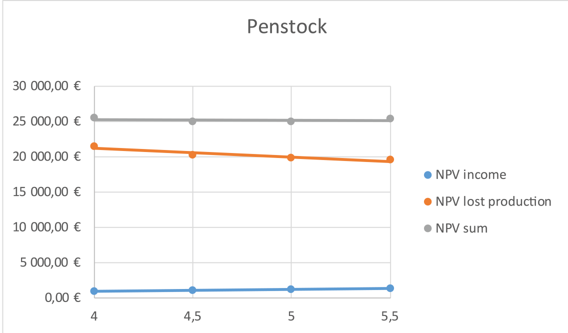
The method described in the previous sections is repeated for the different diameters for both the tunnel and the penstock. We compile the results in the following tables.

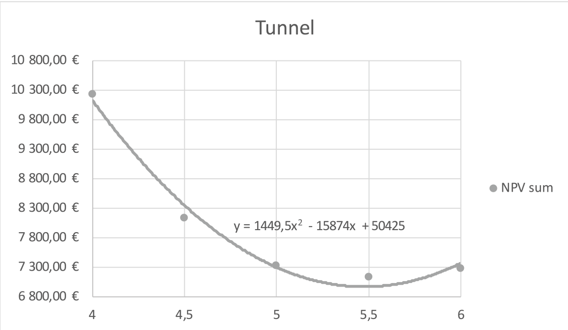
TUNNEL								
Diameter	**Hyraulic loss coef**	**Construction costs**	**Energy loss [m]**	**Energy loss [kW,h]**	**Cost of th lost energy**	**NPV income**	**NPV lost production**	**NPV sum**
4	0,00280722	5125,794	19,9312895	8513,37705	595,936394	953,61 €	6 109,95 €	10 225,83 €
4,5	0,00157935	5843,474	11,2133555	4789,63107	335,274175	1 087,12 €	3 437,46 €	8 129,62 €
5	0,00094587	6561,154	6,71565954	2868,5019	200,795133	1 220,64 €	2 058,69 €	7 327,13 €
5,5	0,00059603	7278,834	4,23183926	1807,57212	126,530048	1 354,16 €	1 297,27 €	7 141,99 €
6	0,00039183	7996,514	2,78198122	1188,28513	83,1799594	1 487,68 €	852,82 €	7 273,81 €

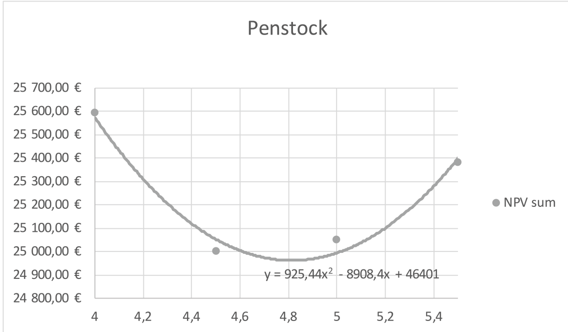
PENSTOCK								
Diameter	**Hyraulic loss coef**	**Construction costs**	**Energy loss [m]**	**Energy loss [kW,h]**	**Cost of th lost energy**	**NPV income**	**NPV lost production**	**NPV sum**
4	0,00085651	5085,794	4,31766782	29968,7799	2097,81459	946,16 €	21 508,25 €	25 592,00 €
4,5	0,00081012	5798,474	4,08380021	28345,5131	1984,18592	1 078,75 €	20 343,25 €	24 999,27 €
5	0,00078929	6511,154	3,97879412	27616,6695	1933,16687	1 211,34 €	19 820,16 €	25 048,45 €
5,5	0,00077975	7223,834	3,93070413	27282,8787	1909,80151	1 343,93 €	19 580,61 €	25 381,15 €

Our interest is then to find an optimal diameter. This is the diameter for which the sum of the NPVs is minimal. We are then interested in the following graphics.









With a simple identification of an extremum with a derivate we find :

- $D_{min,tunnel} = 5,47\text{ m}$
- $D_{min,penstock} = 4,84\text{ m}$