THE USE OF HIGH TEMPERATURE CONDUCTORS IN EXISTING LINES: ECONOMIC AND ENVIRONMENTAL BENEFITS

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ABSTRACT

This paper presents the studies of EDP-Distribuição (EDPD), the Portuguese DSO, in using high temperature conductors in the up-rating of a powerline, in order to reach a significant increase of the transmission capacity, preserving existing corridors and electrical poles.
For the analyses, we took in consideration investment costs, operating costs and environmental benefits.

INTRODUCTION

The high voltage (HV) network is responsible for high power flows between two or more substations, which can reach very high values and so the network configuration should be as meshed as possible.
In the development HV network (60 kV) in response to consumer increase or “N-1” analyses, we can study different alternatives, such as establishment of new powerlines or increasing the capacity of existing powerlines.
In increasing the capacity of the existing powerlines, known as up-rating, we can choose different solutions. Either we can change the mechanical strength of the conductor and the maximum operating temperature, or we can replace the conductors by others with greater ampacity, potentially replacing electrical poles for others with larger mechanical strength [1].
In order to attend to up-rating in a powerline, the traditional method is to substitute the electrical poles and the conductors for the new capacity. In Portugal, the conductors used in this situation are Aluminum Conductor Steel Reinforced (ACSR). However, there is another interesting alternative. We can use high temperature conductors, Aluminum Conductor Composite Core (ACCC), maintaining the existing electrical poles and corridors.
ACCC conductors, compared to ACSR have substantial reduction in thermal sag, reduced weight, higher ampacity and can minimize environmental impact.
In the following table we present the comparison of some of the characteristics of ACCC and ACSR conductors.

Table 1. Characteristics ACSR conductors [2] and ACCC conductors [3]

	Nominal Resistance @ 20ºC	Nominal Resistance @ 75ºC	Nominal Resistance @ 150ºC	Maximum AC Current 70ºC	Maximum AC Current 150ºC	Weight	Corfficient of linear expansion	Rated tensile strength
	(ohm/km)	(ohm/km)	(ohm/km)	(A)	(A)	(kg/km)	(/K)	(kN)
ACCC 380	*0,076*	*0,093*	*0,115*	*797*	*1309*	*1113*	*1,87E-05*	*122,6*
ACSR 326	*0,109*	*0,118*	-	*643*	-	*1214*	*1,77E-05*	*112,7*

Note: *These are the normalized conductors in EDP-Distribuição.*

METHODOLOGIES

Step 1: Define alternatives for the up-rating

The first step is to identify the alternatives to increase the capacity of an existing powerline.

Step 2: Economic analyses

After defining the alternatives, it is necessary to take into account the technical aspects, like material costs, labor, equipment, dismantling an existing powerline, opening of accesses, foundation for the electrical poles, etc.

Step 3: Technical analyzes

At this point we compare the energy losses and capacity in “N-1” operation for the alternatives.

Step 4: Environmental analyzes

Environment analyzes is a fundamental step to understand the impact of the establishment overhead powerline. To understand the impacts for each alternative we analyzed six environmental descriptors.

Step 5: Compare the alternatives (Benefits and Costs)

The last step is to choose the best alternative regarding to economic, technical and environmental aspects.

RESULTS

We made this approach in three project for an up-rating in EDP-Distribuição in the following powerlines:

- Project 1: LN 60 kV Fafe (REN)-Fafe;
- Project 2: LN 60 kV Areias-Vale do Tejo;
- Project 3: LN 60 kV Alfena-Águas do Lever/Vermoim (REN).

<u>Step 1: Define alternatives for the up-rating</u>

Project 1: LN 60kV Fafe (REN) – Fafe

The aim of this project was to insert a new injector in the HV network. The best solution was to open the HV powerline between Felgueiras and Fafe substation. The power flow between the injector and Fafe substation forces to replace the existing powerline, to increase its capacity.
In this situation, we studied two alternatives to increase the capacity of the powerline, as shown in Figure 1.

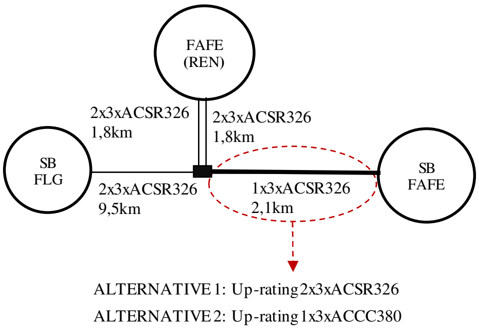

Figure 1. Comparison of the alternatives - Project 1

Project 2: LN 60kV Areias – Vale do Tejo

The aim of this project was to establish a new substation (Areias), and using the existing HV powerlines to feed it. For this propose, the nominal ampacity of a section of the existing powerlines was inadequate.
To increase the capacity of the powerline we studied two alternatives, as shown in Figure 2.

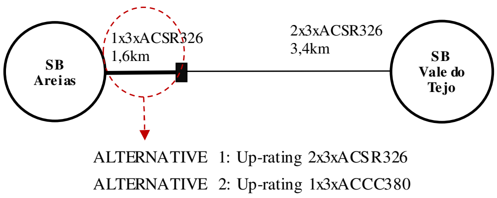

Figure 2. Comparison of the alternatives - Project 2

Project 3: LN 60kV Alfena – Águas do Lever/Vermoin (INJ)

In order to have a double feeder to Alfena substation, this project studied two alternatives. The first alternative was to construct a parallel powerline with ACSR conductors to the existing one and the second alternative was to use the existing poles and substitute the conductors for 2x3xACCC (Figure 3).

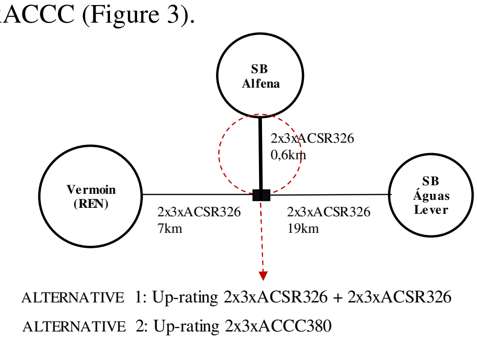

Figure 3. Comparison of the alternatives - Project 3

Step 2: Economic analyzes

For each project we compared the investment in using ACSR conductor and ACCC conductor.
Therefore, to use ACSR conductors, we need to construct a new powerline and dissemble the existing one, which implies the steps registered in Figure 4.

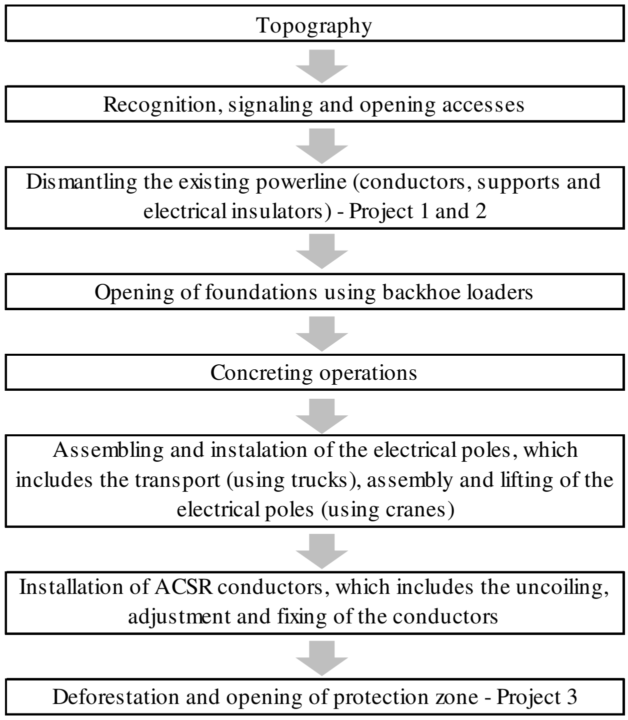

Figure 4. Stages of construction - ACSR up-rating.

In the other hand, the use of ACCC conductors up-rating can eliminate some of this construction steps. In Figure 5, we present the establishment stages of ACCC up-rating.

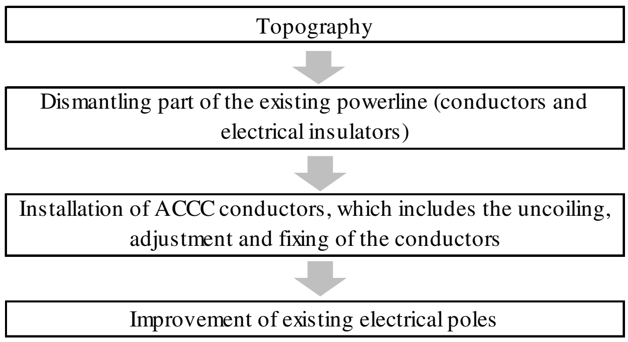

Figure 5. Stages of establishment - ACCC up-rating.

We have analyzed the costs, labor, materials expended, and mechanical equipment used for the different alternatives in the three projects.
Table 2 shown labor and mechanical equipment used in each alternative for the three projects.

Table 2. Summary of the stages of construction in the three projects

		Alternative 1 (ACSR)			Alternative 2 (ACCC)		
	UN	Project 1	Project 2	Project 3	Project 1	Project 2	Project 3
REGISTER AND TOPOGRAPHY POWERLINE	km			0,66			
Delivery truck < 3500 kg	*h*	*0,00*	*0,00*	*6,60*	*0,00*	*0,00*	*0,00*
ASSEMBLY POLES TOPOGRAPHY	km		1,69	0,66			
Delivery truck < 3500 kg	*h*	*0,00*	*11,26*	*4,40*	*0,00*	*0,00*	*0,00*
CONTACT PROPERTIES	un			4,00			
Delivery truck < 3500 kg	*h*	*0,00*	*0,00*	*4,00*	*0,00*	*0,00*	*0,00*
AUTORIZATION PROPERTIES	un			4,00			
OPENING PROTECION CORRIDOR	km			0,30			
Tractor	*h*	*0,00*	*0,00*	*10,80*	*0,00*	*0,00*	*0,00*
Chainsaw	*h*	*0,00*	*0,00*	*21,60*	*0,00*	*0,00*	*0,00*
Delivery truck >3500 kg	*h*	*0,00*	*0,00*	*1,17*	*0,00*	*0,00*	*0,00*
Compressor	*h*	*0,00*	*0,00*	*1,20*	*0,00*	*0,00*	*0,00*
Delivery truck < 3500 kg	*h*	*0,00*	*0,00*	*3,60*	*0,00*	*0,00*	*0,00*
NEW ACCESSES	km	2,16	1,69				
Delivery truck >3500 kg	*h*	*5,41*	*4,22*	*0,00*	*0,00*	*0,00*	*0,00*
Buldozzer assignment	*h*	*5,41*	*4,22*	*0,00*	*0,00*	*0,00*	*0,00*
FONDATIONS	m3	323,10	371,29	251,47			
Excavator assignment	*h*	*171,33*	*196,89*	*133,35*	*0,00*	*0,00*	*0,00*
Compressor assignment	*h*	*42,91*	*49,31*	*33,40*	*0,00*	*0,00*	*0,00*
CONCRETE BLOCKS (C25-30)	m3	74,80	170,54	58,22			
Excavator	*h*	*2,81*	*6,40*	*2,18*	*0,00*	*0,00*	*0,00*
Compressor	*h*	*1,06*	*2,42*	*0,82*	*0,00*	*0,00*	*0,00*
CONCRETE ELECTRICAL POLE<=20T- LABOR	un		3,00				
Buldozzer	*h*	*0,00*	*4,50*	*0,00*	*0,00*	*0,00*	*0,00*
Crane < 35 ton	*h*	*0,00*	*19,59*	*0,00*	*0,00*	*0,00*	*0,00*
Truck with crane 18 ton	*h*	*0,00*	*18,75*	*0,00*	*0,00*	*0,00*	*0,00*
TRANSPORT AND ESTABLISHMENT EP - LABOR	t	59,18	37,49	32,16			
Truck with crane 18 ton	*h*	*167,38*	*106,03*	*90,96*	*0,00*	*0,00*	*0,00*
Excavator	*h*	*43,40*	*27,49*	*23,58*	*0,00*	*0,00*	*0,00*
DISASSEMBLY CONCRETE ELECTRICAL POLE<=10T	un		2,00				
Truck with crane 18 ton	*h*	*0,00*	*5,54*	*0,00*	*0,00*	*0,00*	*0,00*
Excavator	*h*	*0,00*	*5,54*	*0,00*	*0,00*	*0,00*	*0,00*
Crane assignment < 22 ton	*h*	*0,00*	*5,54*	*0,00*	*0,00*	*0,00*	*0,00*
DISASSEMBLY METALIC POLE	t	45,61	40,86				
Truck with crane 18 ton	*h*	*45,15*	*40,45*	*0,00*	*0,00*	*0,00*	*0,00*
Excavator	*h*	*45,15*	*40,45*	*0,00*	*0,00*	*0,00*	*0,00*
DISASSEMBLY CERAMIC CAD	un				39,00	45,00	48,00
DEAD-END INSTALLATION	un	84,00	84,00	48,00	42,00	42,00	42,00
60-ton press	*h*	*42,00*	*42,00*	*24,00*	*21,00*	*21,00*	*21,00*
ASSEMBLY SUSPENSION CLAMPS	un	6,00	6,00		3,00	3,00	
GUARD CABLE: ONE DEAD-END NSTALLATION	un			2,00			
60-ton press	*h*	*0,00*	*0,00*	*1,88*	*0,00*	*0,00*	*0,00*
GUARD CABLE: TWO DEAD-END NSTALLATION	un			3,00			
60-ton press	*h*	*0,00*	*0,00*	*5,40*	*0,00*	*0,00*	*0,00*
ASSEMBLY GUARD CABLE	km			0,66			
Truck with crane 18 ton	*h*	*0,00*	*0,00*	*2,62*	*0,00*	*0,00*	*0,00*
Truck with Tensioner (stringer operation)	*h*	*0,00*	*0,00*	*3,74*	*0,00*	*0,00*	*0,00*
60-ton press	*h*	*0,00*	*0,00*	*3,74*	*0,00*	*0,00*	*0,00*
ASSEMBLY CONDUCTOR	km	12,98	10,13	3,96	6,49	5,07	3,88
Truck with crane 18 ton	*h*	*58,17*	*45,40*	*17,74*	*29,09*	*22,70*	*17,37*
Truck with Tensioner (stringer operation)	*h*	*86,56*	*67,56*	*26,40*	*43,28*	*33,78*	*25,84*
60-ton press	*h*	*86,56*	*67,56*	*26,40*	*43,28*	*33,78*	*25,84*
ASSEMBLY DUMPER	un	84,00	84,00	36,00	42,00	48,00	36,00
REGULATION CONDUCTOR	km			1,20			
Truck with crane 18 ton	*h*	*0,00*	*0,00*	*1,86*	*0,00*	*0,00*	*0,00*
DISASSEMBLY CONDUCTOR	km	8,66	6,76		6,49	5,07	3,82
Truck with crane 18 ton	*h*	*12,69*	*9,90*	*0,00*	*9,52*	*7,43*	*5,59*
IMPROVEMENT ELETRICAL POLES	m				200,00	159,00	100,60
ASSEMBLY TET MECANICAL PROTECIONS	un						1,00

The comparison of total investment for each project has provided some results, shown in Table 3.

Table 3. Comparison of Total Investment.

	Alternative 2 (ACCC) - Alternative 1 (ASCR)		
	Project 1	Project 2	Project 3
Total Investment	*-76,1%*	*-93,8%*	*-24,7%*

ACCC up-rating alternative is low-priced than ACSR up-rating alternative.

Step 3: Technical analyzes

For the technical viewpoint, the main difference between the two alternatives in each project are the HV losses.

The difference of HV losses between the alternatives depends on the conductor resistance. So, as we can see using Table 1, for 75ºC, 1x3xACCC has a bigger resistance than 2x3xACSR, which leads to a higher HV losses.

Another technical difference between the alternatives is the "N-1" operation mode. Since the ACCC conductors have a higher nominal current and can operate at higher temperatures, ACCC alternative is more interesting than ACSR alternative.

Step 4: Environmental analysis

The characterization of the environment affected by the project is fundamental for the correct identification and prediction of the impacts.
This analysis corresponds to the study of the following descriptors:

- Air quality and sound environment;
- Geology and water resources;
- Landscape and visual impact;
- Flora and line protection corridor;
- Soil morphology;
- Materials and waste.

Air quality and sound environment

The use of mechanical equipment in electrical powerlines construction is responsible for three types of environmental problems:

- Fossil fuels consumption and carbon dioxide (CO_2) emissions;
- Atmosphere pollution with noxious gases and particles;
- Increased noise pollution;

Exhaust gases from work equipment contain carbon dioxide, a greenhouse gas that is responsible to global warming.
Harmful gases from the exhaust of mechanical equipment contain dangerous molecules for human health, such as carbon monoxide, sulphur oxides and nitrogen oxides.
Fuel emissions of CO_2 (2.68 kg/litre [4]), can be obtain from the operation hours of the mechanical equipment (Table 2) and its average consumption per operation hour. The Table 4 presents for each project and alternative, the litres of diesel fuel spent. The ACCC up-rating alternative have a significant reduction in the burning of this fossil fuel and consequently CO_2 greenhouse gas emissions reduction.

Table 4. Diesel fuel burn, CO2 emissions and working equipment hour, pear project.

	Alternative 1 (ACSR)			Alternative 2 (ACCC)		
	Project 1	Project 2	Project 3	Project 1	Project 2	Project 3
Diesel fuel (litres)	6810	6602	3412	1052	840	662
Diesel fuel (kg CO2)	18182	17626	9110	2810	2244	1769
Mechanical Equip. (hour)	451	771	803	96	111	137

The working equipment used in powerlines construction, is a source of noise pollution, which is the cause of stress in workers and the populations. The mechanical equipment noise can be frightening to the animals, forcing them run away from their natural habitats. Although, the noise pollution in this type of work is normally low impact and can be controllable, the ACCC up-rating alternative represents a less impactful alternative, because of the non-use of some mechanical equipment (Table 4).

Geology and water resources

The manufacture of concrete used in the foundations of the electrical poles is the main water consumption in powerline construction. In concrete plants, water consumption is around 170 litre/m3 [5].
The concrete production have multiple impacts on the environment. It uses large quantities of gravel and sand, and the production process releases large amounts of CO2. For the ACCC up-rating alternative the use of concrete was null, because it has no assemble of electrical poles. In Table 5 is presented the concrete and water consumption in each project.

Table 5. Concrete and water per project

	Alternative 1 (ACSR)			Alternative 2 (ACCC)		
	Project 1	Project 2	Project 3	Project 1	Project 2	Project 3
Concrete (m3)	75	171	58	0	0	0
Water (litres)	12716	28992	9897	0	0	0

Landscape and visual impact

For the visual impact assessment, is important the study the visibility, that can be done by identifying areas of visual influence and visibility basin, as well the landscape quality and visual absorption capacity. The impact magnitude can be high, medium, low or zero.
For project 1 and 2, in both alternatives the impact is zero, since the electrical infrastructure already exists and the powerline physical modification does not change the present visual impact. This is also true for project 3 ACCC up-rating alternative.
In project 3 ACSR up-rating alternative, the visual impact of this new structure will be low, because of the existence of a parallel infrastructure.

Flora and line protection corridor

In order to guarantee the safe operation of powerlines, the High Voltage Safety Regulation for Electrical Powerlines (Decreto Regulamentar 1/92, of February 18) [6], establishes the constitution of the protection corridor under electric powerlines. For high voltage (60kV) powerlines, this corridor must have a minimum of 25 meters wide, where we have to cut or decouple the all the trees, ensuring the minimum safety distance.
In project 3, the ACSR up-rating alternative was to construct a new powerline, parallel to the existing one, which would imply the deforestation of 7500 m2, Table 6. The ACCC up-rating alternative allowed maintaining the entire existing flora in those 7500 m2.

Table 6. Tree protection range per project

	Alternative 1 (ACSR)			Alternative 2 (ACCC)		
	Project 1	Project 2	Project 3	Project 1	Project 2	Project 3
Tree protec. range (m2)	0	0	7500	0	0	0

Soil morphology

The need of mechanical equipment for electrical poles transportation, foundations and concreting, forces new accesses establishments. This represents an impact for the fauna and existing flora, and a possible impact on soil first layer.
The choice of the ASCR up-rating alternative may lead to forest fragmentation, soil stabilization problems and changes in structure of ecosystems, landscape and soil morphology.
The choice of ACCC up-rating alternative will represent a huge reduction in fauna and flora impacts. In this alternative, there is no need of foundations and new accesses establishment. In Table 7, we can verify the cubic meter of soil moved in foundations, as well as the length of the accesses in each project / alternative.

Table 7. Soil impacts per project

	Alternative 1 (ACSR)			Alternative 2 (ACCC)		
	Project 1	Project 2	Project 3	Project 1	Project 2	Project 3
Excavation soil (m3)	323	371	251	0	0	0
Road excavation (m)	108	84	33	0	0	0

Materials and waste

The main ferrous and non-ferrous metal used in the powerline construction are iron, steel and aluminum, for the electrical poles and conductors manufacture.
The manufacture of these two fundamental elements is also responsible for an environmental impact. The extraction of raw materials from nature causes huge changes in the landscape, and the manufacture, implies huge expenditures of primary energy and CO2 emissions.
The use of ACCC up-rating alternative allows the rehabilitation of electrical poles, enabling better environmental indicators than the ACSR up-rating alternative.
Table 8 quantifies the amount of new materials and recycling waste generated, in the different projects and alternatives.

Table 8. Materials: Electrical poles and conductors

	Alternative 1 (ACSR)			Alternative 2 (ACCC)		
	Project 1	Project 2	Project 3	Project 1	Project 2	Project 3
Metalic towers (kg)	*59180*	*37490*	*32160*	*0*	*0*	*0*
Conductors cable (m)	*12984*	*10134*	*4620*	*6492*	*5067*	*3876*
Waste iron (kg)	*45610*	*40855*	*0*	*0*	*0*	*0*
Waste conductors (m)	*8660*	*6760*	*0*	*6490*	*5070*	*3816*

Step 5: Compare the alternatives (Benefits and Costs)

The Table 9 presents the variation of total costs between Alternative 2 and Alternative 1, in each project.

Table 9. Economic comparison of the alternatives.

Alternative 2 (ACCC) - Alternative 1 (ASCR)			
	Project 1	Project 2	Project 3
Total Costs**	*-25,9%*	*-43,8%*	*-16,3%*

(**) Operating costs(for equipment life cicle) + Investment costs

The ACCC up-rating alternative is less onerous than ACSR up-rating.
In order to determinate which conductor we should choose in an up-rating, we can observe the following formula (1) and Figure 6, that compares the investment and the HV losses.

$$3 \times (R_{ACCC} - R_{ACSR}) \times km \times I^2 \times K < |\Delta Investment| \quad (1)$$

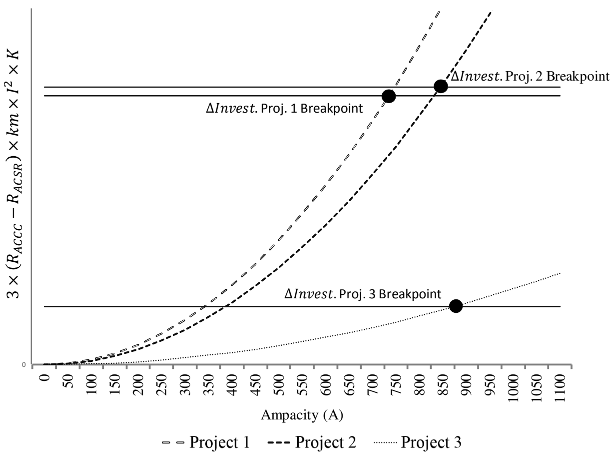

Figure 6. Relation between Δinvestment and HV losses – ACCC vs ACSR conductors in up-rating.

- **I** is the ampacity;
- **km** is the length of the powerline
- **ΔInvestment** is the difference between the total investment using ACCC conductor or ACSR conductor;
- **K** is the appreciation of HV losses during the conductor life cycle;
- $\boldsymbol{R_{ACSR}}$ and $\boldsymbol{R_{ACCC}}$ are the resistance of the conductors at 75ºC.

The breakpoint represents the value where ΔInvestment equals the ΔHV losses. For each project, until the breakpoint is reached the ACCC up-rating is the best alternative.
Regarding the environmental benefits, we present on Table 10 the comparison between each alternative for the environmental descriptors.

Table 10. Environmental indicator per km

Alternative 1 (ACSR) - Alternative 2 (ACCC) per km			
	Project 1	Project 2	Project 3
Diesel (liters)	*2661*	*3411*	*4166*
CO2 (ton)	*7*	*9*	*11*
Concrete (m3)	*35*	*101*	*88*
Water (m3)	*6*	*17*	*15*
Excavation soil (m3)	*149*	*220*	*381*
Road excavation (m)	*50*	*50*	*50*
Metalic towers (ton)	*27*	*22*	*49*
Conductors cable (km)	*3*	*3*	*1*
Waste iron (ton)	*21*	*24*	*0*
Waste conductors (km)	*1*	*1*	*-6*

The use of ACCC conductors in up-rating reduces almost all the factors of the environmental analyses.
In conclusion, for the three projects, the ACCC up-rating alternative provides better environmental benefits.

CONCLUSIONS

This paper presents the comparison in using ACCC conductors or ACSR conductors in a powerline up-rating.
In the three projects, we have an economic advantage in using ACCC conductors, although it has higher high voltage losses.
The ACCC conductor up-rating has several positive environmental indicators that are important for the final decision under study alternatives.
Choosing from one alternative or another could take into account total investments, HV losses but also environmental benefits.

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