Deliverable 2.1.2

Detailed Project Description

09 - TREY Turkey - Egypt

EC DEVCO - GRANT CONTRACT: ENPI/2014/347-006

“Mediterranean Project”

Task 2 “Planning and development of the Euro-Mediterranean Electricity Reference Grid ”

Med-TSO is supported by the European Union.

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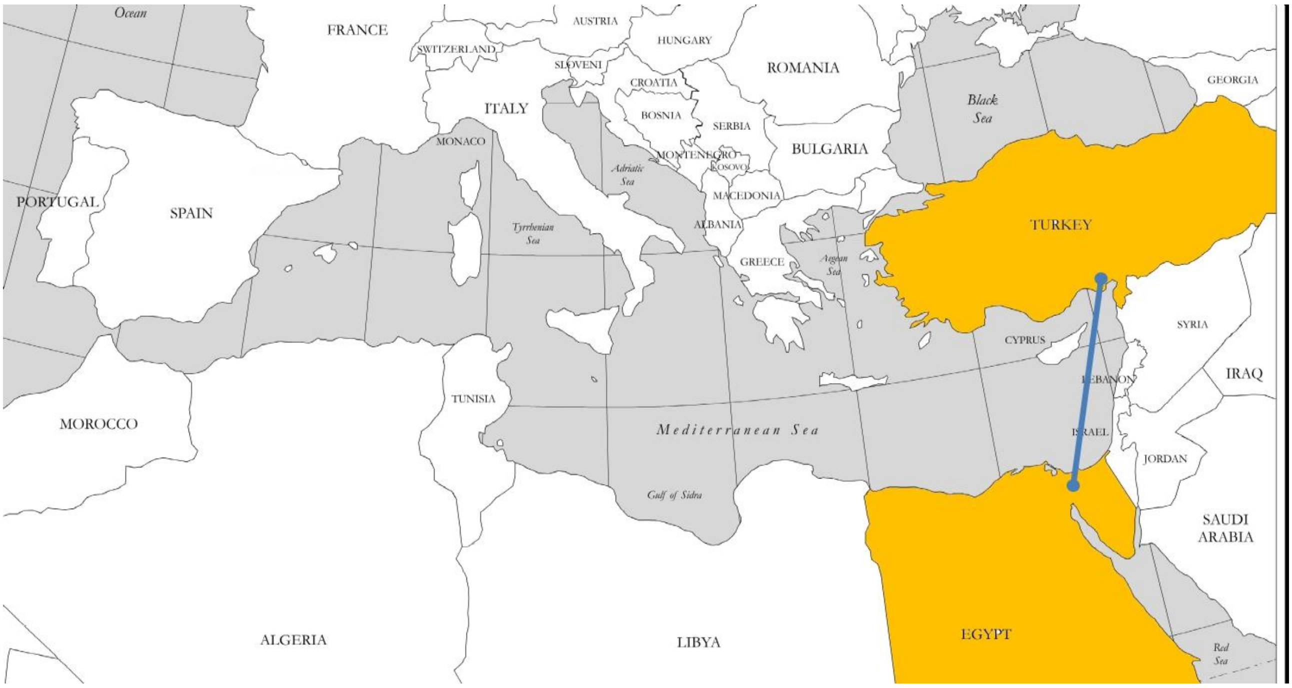
1 Introduction

The present document contains the studies on project TREY, in the context of the Mediterranean Master Plan of Interconnections. Project TREY consists of a new interconnection between Turkey and Egypt (+3000 MW DC).

The document is structured as follows. Section 2 describes in detail the interconnection project and the different sources for data employed. Section 3 presents the definition of the different snapshots to be considered and the description of the building process followed. Section 4 comprises the criteria and results of the security analysis. Section 5 summarizes the results on security analysis and reinforcements' assessment. Section 6 contains the estimations made for the active power losses. Finally, section 7 comprises the estimation for the different investment costs.

2 Project description and data acquisition



The project consists in one new interconnection between Turkey and Egypt, to be realized through a submarine 3000 MW HVDC link. For this project, only the Turkish system has been considered as full represented by its transmission network model. Boundary systems, i.e. Greece, Bulgaria, Syria and Egypt, are considered as external buses with loads to simulate energy interchanges.

***Project* details**							
Description	***Substation (from)***	***Substation (to)***	***GTC contribution (MW)***	***Present status***	***Expected commissioning date***	***Evolution***	***Evolution driver***
New interconnection between Turkey and Egypt (HVDC)	Turkey (TR) Bezci	Egypt (EY) -	2000	Long-term project	Project under consideration		Develop a new corridor in the eastern Mediterranean

The system defined for project TRIS is described in the table and figure below.

Full models	Boundaries
Turkey TR	Egypt EY
	Greece GR
	Bulgaria BG
	Syria SY

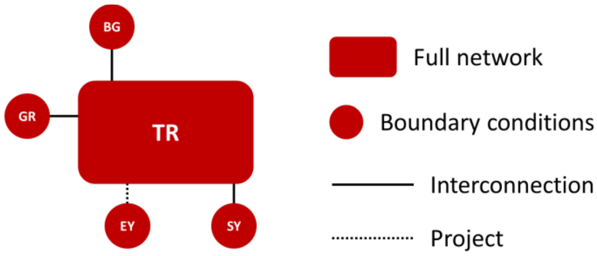


Table 1 – Participation of each of the systems involved in project TREY

In the snapshots definition, 4 scenarios (S1, S2, S3 and S4) and seasonality (Winter/Summer) were distinguished, based on the distinctively different assumptions of future evolution considered in the Mediterranean project.

In data collection, a set of eight full models were provided for the Turkish system, corresponding with 4 scenarios and seasonality (Winter/Summer). Full list of provided files is included in [1].

Technologies for generating units have been specified in all systems with respect to the generating technologies considered in the Mediterranean project, while all generating units of the same technology were considered with the same rank. In all models provided interconnected Areas were well identified.

Merging process consists of joining the different networks using the connecting buses defined in the next tables. Table 2 shows the set of interconnections that correspond with pairs formed by a modelled system and a boundary system, thus only one bus in the modelled system needs to be identified.

Bus	Area (from)	Substation	Area (to)
XNS_BA11	Turkey TR	Babaeski	Greece GR
XMI_HA11	Turkey TR	Hamitabat	Bulgaria BG
XMI_HA12	Turkey TR	Hamitabat	Bulgaria BG
XAL_BR11	Turkey TR	Birecik	Syria SY

Table 2 – Points of merging between systems and external buses in the TREY project

Finally, Table 3 presents the new interconnection associated to the TREY project, placed at bus XEG_AD11.

PROJECT	Bus	Area	Subs.	Bus	Area	Subs.	LINK
TREY	XEG_AD11	Turkey TR	Bezci	-	Egypt EY	-	HVDC

Table 3 – Points of merging in the Projects in the TREY project

3 Snapshots definition and building process

For the project TREY, a total number of nine Points in Time (PiT) have been defined [2]. Each of the PiT contains, for each of the systems considered, the active power generated, demanded and exported to the other systems. Active power production comes with a breakdown of technologies. Next table shows the power balance for each of the PiTS in TREY project.

project TREY PiT 1 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	EY
Turkey TR	66709.1	63853.0	107.0	2963.2	0.0	-209.4	-427.4	600.0	3000.0

project TREY PiT 2 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	EY
Turkey TR	31672.8	27365.9	219.0	4525.8	0.0	563.9	361.9	600.0	3000.0

project TREY PiT 3 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	EY
Turkey TR	54677.2	53841.3	234.0	1069.9	0.0	206.3	1296.1	600.0	-1032.6

project TREY PiT 4 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	EY
Turkey TR	82159.4	80666.4	107.0	1600.0	0.0	-660.0	-1340.0	600.0	3000.0

project TREY PiT 5 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	EY
Turkey TR	37952.7	34571.7	219.0	3600.0	0.0	0.0	0.0	600.0	3000.0

project TREY PiT 6 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	EY
Turkey TR	68330.3	70874.2	164.0	-2379.9	0.0	-660.0	-689.4	-2.3	-1028.3

project TREY PiT 7 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	EY
Turkey TR	42724.7	42013.7	191.0	902.1	0.0	-40.5	982.4	-5.2	-34.7

project TREY PiT 8 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	EY
Turkey TR	41585.1	40675.9	92.0	1001.2	0.0	-660.0	-367.5	600.0	1428.8

project TREY PiT 9 - Power Balance [MW]

sys	PG	PD	Pextra	Pexport	TR	GR	BG	SY	EY
Turkey TR	43328.7	42014.3	30.0	1344.4	0.0	-660.0	-925.1	600.0	2329.5

Table 4 – Power balance for each of the PiTS defined in the TREY project

In Table 4, the column ‘Pextra’, only non-zero for the Turkish system, represents extra energy that comes from Georgia, Iran and Iraq.

4 Power flow and security analysis

This section presents the criteria agreed to run the power flow and security analysis over the different snapshots built for project TREY. Details on the methodology used for the security analysis are compiled in [3].

Turkey

For the Turkish system, the perimeter of the security analysis was limited in the bulk transmission level. Therefore, the branches considered for the N-1 analysis but also as the monitored elements were only those at 400 kV.

Concerning rates and tolerances, from the three different values identified in the models provided, i.e. rateA, rateB and rateC, for lines, rateB was considered for Summer and rateA for Winter, while rateC was not taken into consideration. The tolerance considered for overload was 0% for all branches in N situations and +10% in N-1 situations.

Regarding the loss of generating units, the energy lost was compensated internally, using the rest of Turkish generating units.

Finally, a set of N-2 outages has been specified for the project TREY. This set is formed by two different clusters of lines:

'Sinop NPP' set				'Akkuyu NPP' set		
bus FROM	bus TO	IC		bus FROM	bus TO	IC
TALTIN11 400,00	TSINPN11 400,00	1		TKONYA11 400,00	TAKKYN11 400,00	1
TKURSN11 400,00	TSINPN11 400,00	1		TKRMND11 400,00	TAKKYN11 400,00	1
TKURSN11 400,00	TSINOP11 400,00	1		TSEYDS11 400,00	TAKKYN11 400,00	1
TSINOP11 400,00	TSINPN11 400,00	1		TERMEN11 400,00	TAKKYN11 400,00	1
TKSTMN11 400,00	TSINPN11 400,00	1		TMERSN11 400,00	TAKKYN11 400,00	1
TBARTN11 400,00	TKSTMN11 400,00	1		TMNVGT11 400,00	TAKKYN11 400,00	1
TBARTN11 400,00	TSINPN11 400,00	1				

Table 5 – N-2 outages considered for the Turkish system in project TREY

From each of the sets, N-2 considered the simultaneous outage of two lines.

5 Assessment of reinforcements

Reinforcements that are required to secure operation of Turkish grid with the TREY interconnection project could be listed in two categories: 1. upgrade of existing OHL and 2. Addition of new OHL/addition of new connection point to existing OHL.

To increase transmission capacity of an existing 2-bundle OHL, existing route needs to be replaced with 3-bundle Pheasant OHL. Parameters of 3-bundle Pheasant OHLs are listed in the table below.

	Rs [pu/100km]	Xs [pu/100km]	Bp [pu/100km]	rateA [MVA]	rateB [MVA]	rateC [MVA]
3-bundle Pheasant OHL	0,000994	0,016437	0,703719	1921	1604	2610

Table 6 – Parameters of 3-bundle Pheasant OHLs for the project TREY

With the TREY interconnection project, 2-bundle OHLs required to be upgraded are listed below:

- 400 kV Adana - Bastug OHL - 2bundle Cardinal, 59 km
- 400 kV Tosçelik - Bastug OHL - 2bundle Cardinal, 4 km
- 400 kV Erzin - Tosçelik OHL - 2bundle Cardinal, 13 km
- 400 kV Erzin - Andirin OHL - 2bundle Cardinal, 73 km

To reinforce Turkish grid in the vicinity of TREY interconnection project's connection point, connection of planned 400kV Kozan - Sanko TES OHL (3bundle Pheasant, 75km) should be modified by connecting this OHL to Misis OSB substation (geographically between Kozan and Sanko TES substations) with addition of 25 km new OHL. After modification process, Kozan - Sanko TES OHL would be operated as 400kV Kozan - Misis OSB OHL (3bundle 60km Pheasant OHL) and 400kV Misis OSB - Sanko TES (3bundle 40km Pheasant OHL).

Relevant overloads were resolved with selected reinforcements. Next figure shows the map of the new interconnections (yellow line) and relevant internal reinforcements that were identified in the security analysis (green line).

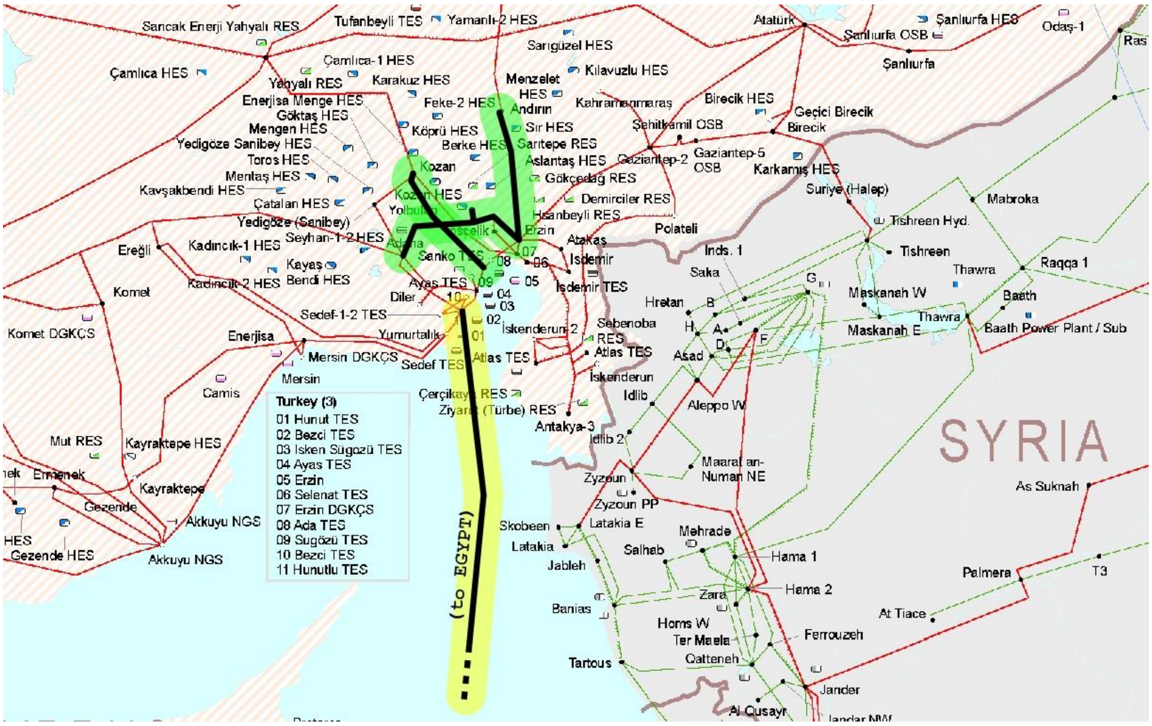


Figure 1 – Map of interconnections and reinforcements for project TREY

6 Estimation of Active Power Losses

Internal losses in each country

To evaluate the performance of the new interconnection projects plus the planned reinforcements, the active power losses have been computed for 1) the snapshots built with the specified reinforcements considered, and for 2) the snapshots without interconnection projects and without reinforcements. Next table shows the active power losses summary for each of the PiTs.

	Power losses [MW]		
PiT	Without proj&reinf	With proj&reinf	Difference (W-WO)
1	1319.1	1171.8	-147.3
2	372.2	438.0	65.8
3	1061.0	1066.1	5.2
4	1550.1	1341.4	-208.7
5	378.0	440.1	62.2
6	885.9	1038.2	152.3
7	314.3	313.1	-1.2
8	703.0	729.3	26.2
9	340.1	428.0	87.9

Table 7 – Comparison of the active power losses for each snapshot, with and without interconnection projects and reinforcements

Taking into account the time percentile (hours of the year) that each PiT represents, internal active power losses with and without the new interconnection project computed for each PiT have been converted to annual energy losses for each one of the 4 scenarios. The following table shows the annual internal delta losses estimate for the system of Turkey:

Scenario	Annual Internal Losses (MWh)
	TR
S1	229,285
S2	229,285
S3	229,285
S4	229,285

Table 8 – Annual internal delta losses estimate for TR

Losses in the new HVDC interconnection

Based on the hourly time series of exchange among countries provided by Market studies for each one of the 4 scenarios, with and without the new interconnection project, yearly losses on the interconnection have also been computed.

Computation of the losses in the new HVDC interconnection has been carried out for the four scenarios S1 to S4 and 8760 hours of estimated flows through the interconnections. The following table summarizes the values used for this estimation exercise:

V_{nom} [kV]	r_l [Ω/100km]	A (MW/kA)	B (kW)	d (km)
500	0.600	2.2	3.1	700

Table 9 – Parameters for the losses estimation in the TREY interconnections

The following table shows the annual losses estimate on the interconnection project for each scenario:

Scenario	Annual Losses on Interconnection (MWh)
	EY-TR
S1	1,093,318
S2	706,156
S3	495,438
S4	640,359

Table 10 – Annual losses estimate for the new TREY interconnection

Both internal losses and losses on the interconnection were monetized for each scenario, taking into account the Annual Average Value of Marginal Cost, for the countries involved, as provided by the Market Studies. Results are presented in the following table:

Scenario	Annual cost of losses (M€)				Total Interconnection (M€)	Total System (M€)	Total M€)
	TR			EY			
	Interconnection	System	Total	Interconnection			
S1	35.97	15.09	51.06	35.97	71.94	15.09	**87.03**
S2	28.88	18.76	47.64	28.88	57.76	18.76	**76.52**
S3	17.93	16.60	34.54	17.93	35.87	16.60	**52.47**
S4	26.88	19.25	46.13	26.88	53.76	19.25	**73.01**

Table 112 – Annual cost of losses estimate for the new TREY interconnection

As a general remark, in addition to the losses on the HVDC interconnection the project results in an increase also of the internal losses.

7 Estimation of Investment Cost

The new HVDC link between Turkey and Egypt is expected to be implemented using VSC technology, which presents several advantages over the LCC technology that cannot be directly quantified but should be taken into account [4]:

- Active and reactive power can be controlled independently. The VSC is capable of generating leading or lagging reactive power, independently of the active power level. Each converter station can be used to provide voltage support to the local AC network while transmitting any level of active power, at no additional cost;
- If there is no transmission of active power, both converter stations operate as two independent static synchronous compensators (STATCOMs) to regulate local AC network voltages;
- The use of PWM with a switching frequency in the range of 1–2 kHz is sufficient to separate the fundamental voltage from the sidebands, and suppress the harmonic components around and beyond the switching frequency components. Harmonic filters are at higher frequencies and therefore have low size, losses and costs;
- Power flow can be reversed almost instantaneously without the need to reverse the DC voltage polarity (only DC current direction reverses).
- Good response to AC faults. The VSC converter actively controls the AC voltage/current, so the VSC-HVDC contribution to the AC fault current is limited to rated current or controlled to lower levels. The converter can remain in operation to provide voltage support to the AC networks during and after the AC disturbance;
- Black-start capability, which is the ability to start or restore power to a dead AC network (network without generation units). This feature eliminates the need for a startup generator in applications where space is critical or expensive, such as with offshore wind farms;
- VSC-HVDC can be configured to provide faster frequency or damping support to the AC networks through active power modulation;
- It is more suitable for paralleling on the DC side (developing multiterminal HVDC and DC grids) because of constant DC voltage polarity and better control.

Based on the information on the interconnection project and the relevant internal reinforcements that were identified in the security analysis the total investment cost was estimated as presented in the following tables. As a general remark, internal reinforcements In Turkey associated with the project are rather shallow (close to the point of connection), representing a very small part of the investment cost (2%).

The following tables provide an estimate for the investment cost for the internal reinforcements, and the Cost Benefit Analysis (CBA) carried out based on the results of EES and TC1 activities of the Mediterranean Project. It should be noted that this is an estimation of the cost based on the best practices in the region.

P9 - TREY - Investment Cost								
New Interconnections								
Description	**Type**	**Countries Involved**	**Length/number**		**Total Investment Cost**	**GTC Contribution**	**Location**	**Status**
			OHL [km]	**Cable [km]**	**M€**	**MW**		
New interconnection Turkey-Egypt	HVDC Submarine Cable	TR-EY	-	700	2058	3000	S TR - N EY	Long-term
	HVDC Converter Station in Turkey	TR	1		416		S TR	Long-term
	HVDC Converter Station in Egypt	EY	1		416		N EY	Long-term
Total Cost of New Interconnections (M€ / %total)					**2890**	**99%**		
Internal Reinforcements								
Description	**Type**	**Countries Involved**	**Length/number**		**Total Investment Cost**	**Capacity**	**Location**	**Status**
			OHL [km]	**Cable [km]**	**M€**	**MW / MVA**		
Replacement of conductors AC OHL 400kV 2-bundle Adana - Bastug	AC OHL 400kV - 3-bundle	TR	59	-	7.1	1921-2610	S TR	Long-term
Replacement of conductors AC OHL 400kV 2-bundle Tosçelik - Bastug	AC OHL 400kV - 3-bundle	TR	4	-	0.5	1921-2610	S TR	Long-term
Replacement of conductors AC OHL 400kV 2-bundle Erzin - Tosçelik	AC OHL 400kV - 3-bundle	TR	13	-	1.6	1921-2610	S TR	Long-term
Replacement of conductors AC OHL 400kV 2-bundle Erzin - Andirin	AC OHL 400kV - 3-bundle	TR	73	-	8.8	1921-2610	S TR	Long-term
Total Cost of Internal Reinforcements (M€ / %total)					**18**	**1%**		
Total Project Investment Cost					**2908**			

Table 12 – Investment costs of the project TREY

Assessment results for the Cluster P9 - TREY														
non scenario	GTC increase direction 1 (MW)		3000											
	GTC increase direction 2 (MW)		3000											
scenario specific			MedTSO scenario											
			1			2			3			4		
			Ref. Scenario	with new project	Delta	Ref. Scenario	with new project	Delta	Ref. Scenario	with new project	Delta	Ref. Scenario	with new project	Delta
GTC / NTC (import)		TR	6200	9200	3000	6200	9200	3000	6200	9200	3000	6200	9200	3000
		EY	1250	4250	3000	1250	4250	3000	1250	4250	3000	1250	4250	3000
Interconnection Rate (%)*		TR	4.9%	7.3%	2.4%	4.9%	7.2%	2.4%	4.4%	6.5%	2.1%	4.1%	6.0%	2.0%
		EY	1.4%	4.9%	3.4%	1.4%	4.9%	3.4%	1.3%	4.5%	3.2%	1.4%	4.7%	3.3%
Benefit Indicators	B1-SEW	(M€/y)	880			440			470			370		
	B2-RES	(GWh/y)	0			0			0			0		
	B3-CO_2	(kT/y)	4900			-850			-1800			-1100		
	B4 - Losses	(M€/y)	84.1			75.5			51.5			72.6		
		(GWh/y)	1323			935			725			870		
	B5a-SoS Adequacy	(MWh/y)	0			0			500			20		
	B5b-SoS System Stability													
Residual Impact Indicators	S1- Environmental Impact													
	S2-Social Impact													
	S3-Other Impact													
Costs	C1-Estimated Costs	(M€)	2908											

* considering the GTC for 2030 , the Install generation for 2030 and the GTC for importation (the same criteria used in the ENTSO-E)

Rules for sign of Benefit Indicators	
B1- Sew [M€/year] =	Positive when a project reduces the annual generation cost of the whole Power System
B2-RES integration [GWh/Year] =	Positive when a project reduces the amount of RES curtailment
B3-CO_2 [kt/Year] =	Negative when a project reduces the whole quantity of CO_2 emitted in one year
B4-Losses - [M€/Year] and [GWh/Yea	Negative when a project reduces the annual energy lost in the Transmission Network
B5a-SoS [MWh/Year] =	Positive when a project reduces the risk of lack of supply

Assessment	Color code
negative impact	red
neutral impact	light pink
positive impact	green
Not Available/Not Available	grey
monetized	yellow

Table 13 – Results of the Cost Benefit Analysis for the TREY project

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8 References

1	Snapshots building process	Share point
2	Guide for setting up grid models for Network studies	Share point
3	Network Analysis and Reinforcement Assessment	Share point
4	D. Jovcic and K. Ahmed, "Introduction to DC Grids," in High-Voltage Direct-Current Transmission, John Wiley & Sons, Ltd, 2015, pp. 301–306.	Share point

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