Deliverable 2.1.2

Detailed Project Description

14 - GRCYIS Greece-Cyprus-Israel

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

"Mediterranean Project"

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

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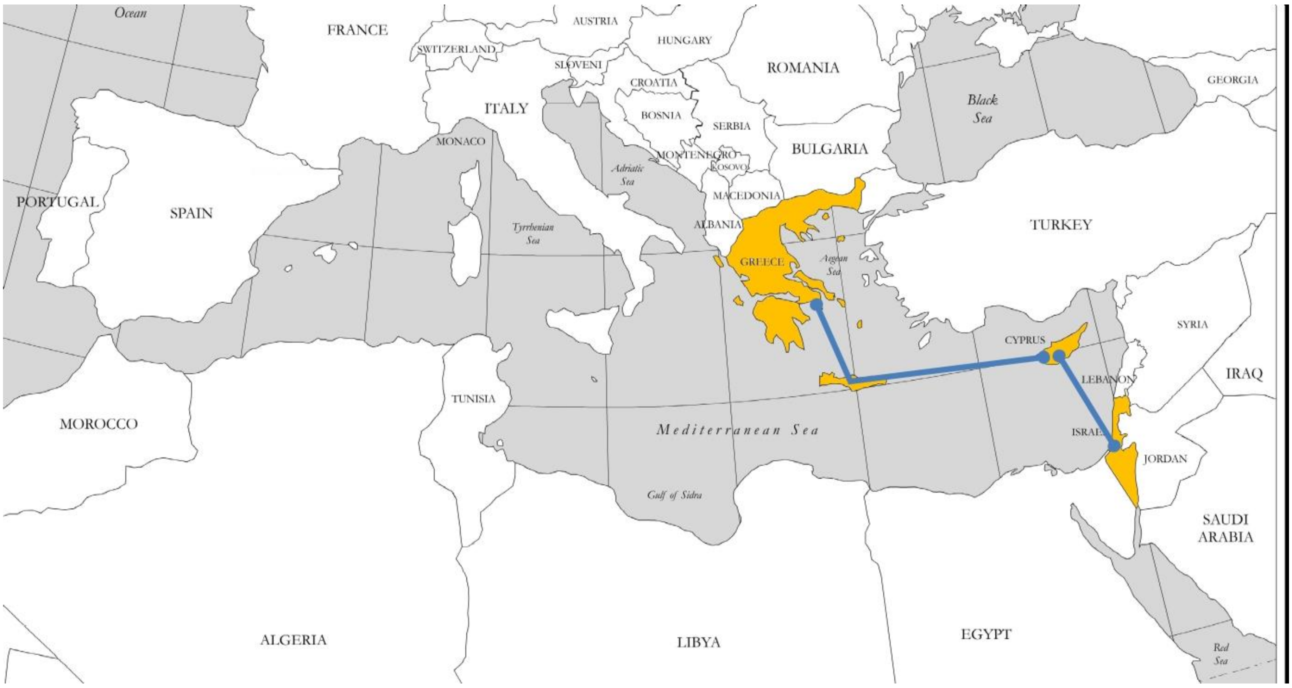
1 Introduction

The present document contains the studies on project GRCYIS, in the context of the Mediterranean Master Plan of Interconnections. Project GRCYIS consists of new HVDC interconnections between Greece and Cyprus (+2000 MW DC) and between Cyprus and Israel (+2000 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 Euro Asia Interconnector consists of a HVDC VSC 500 kV submarine electric cable and any essential equipment and/or installation for interconnecting the Cypriot, Israeli and the Greek transmission networks (offshore). The Interconnector will have a capacity of 2000 MW and a total length of around 832 nautical miles/around 1541 km (approx. 314 km between Cyprus and Israel, 894 km between Cyprus and Crete and 333 km between Crete and Athens) and allow for reverse transmission of electricity.

Project details

Description	*Substation (from)*	*Substation (to)*	*GTC contribution (MW)*	*Present status*	*Expected commissioning date*	*Evolution*	*Evolution driver*
EuroAsia Interconnector - new interconnection between Greece, Cyprus and Israel (HVDC)	Greece (GR) Athens Cyprus (CY) Vassilikos	Cyprus (CY) Vassilikos Israel (IS) -	2000	Planned (PCI TYNDP ENTSO-E)	1st Stage 1000MW • Athens – Damasta (2020) • Damasta – Vassilikos (2021) • Vassilikos – Hadera (2021)	Studies completed, 1st Stage 1000MW Athens – Damasta included in the TYNDP of IPTO (2023)	Create the electricity highway Israel-Cyprus-Greece and end the energy isolation of Cyprus

The systems involved in the project GRCYIS are described in the table and figure below.

Full models	Boundaries
Greece GR	Albania AL
Cyprus CY	Italy IT
	Israel IS
	FYROM FY
	Bulgaria BG
	Turkey TR

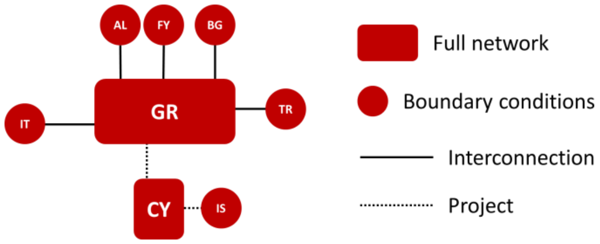


Table 1 – Participation of each of the systems involved in project GRBGTR

Concerning the representation of the systems in the model used for this project, the Greek and Cyprus systems have been considered as fully represented by their transmission network models, while boundary systems, i.e. Albania, Italy, Israel, FYROM[1], Bulgaria and Turkey, were considered as external buses with loads to simulate energy interchanges.

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, the following models were provided:

- For the Greek system, a set of eight full models, corresponding with 4 scenarios and seasonality (Winter/Summer).
- For the Cyprus system, a set of two full models, corresponding with seasonality (Winter/Summer). The models represent the current situation of 2017. System reinforcements that occur from the approved Cyprus Ten Year Network Development Plan 2018-2027 were also provided.

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 are well identified.

Merging process consists of joining the different networks using the connecting buses defined in the next tables. First, 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.

[1] FYROM corresponds with 'Former Yugoslavian Republic of Makedonia'

Bus	Area (from)	Substation	Area (to)
XBG_TH11	Greece GR	Thessaloniki	Bulgaria BG
XMI_NS11	Greece GR	Maritsa Iztok	Bulgaria BG
XNS_BA11	Greece GR	N. Santa	Turkey TR
XZE_KA11	Greece GR	Kardia	Albania AL
XBI_MO31	Greece GR	Mourtos	Albania AL
XFL_BI11	Greece GR	Theassloniki	FYROM FY
XTH_DU11	Greece GR	Amyndeo	FYROM FY
XAR_GA1G	Greece GR	Arachthos	Italy IT

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

Finally, Table 3 presents the new interconnections associated to the GRCYIS project.

PROJECT	Bus	Area	Subs.	Bus	Area	Subs.	LINK
GRCYIS	XKO_VA	Greece GR	Athens	132 KV - BSE	Cyprus CY	Vassilikos	HVDC
GRCYIS	132 KV - BSE	Cyprus CY	Vassilikos	-	Israel IS	-	HVDC

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

In project GRCYIS, two DC links were considered. For the first link (Greece-Cyprus), the bus XVO_VA was identified in Greek network. In the Cyprus system, bus 132 KV – BSE has been identified for both of the projected links, i.e. the Greece-Cyprus and the Cyprus-Israel.

3 Snapshots definition and building process

For the project GRCYIS, a total number of two 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 GRCYIS project.

project GRCYIS PiT 4 - Power Balance [MW]

sys	PG	PD	Pexport	GR	CY	AL	IT	MK	TR	BG	IS
Greece GR	9065.9	7307.4	1758.5	0.0	309.1	209.0	-500.0	212.3	494.1	1034.0	0.0
Cyprus CY	671.7	949.3	-277.6	-309.1	0.0	0.0	0.0	0.0	0.0	0.0	31.4

project GRCYIS PiT 5 - Power Balance [MW]

sys	PG	PD	Pexport	GR	CY	AL	IT	MK	TR	BG	IS
Greece GR	10787.6	7709.2	3078.4	0.0	1330.3	240.3	453.1	117.7	0.0	937.0	0.0
Cyprus CY	1213.8	544.1	669.7	-1330.3	0.0	0.0	0.0	0.0	0.0	0.0	2000.0

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

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 GRCYIS. Details on the methodology used for the security analysis are compiled in [3].

Greece

For the Greek 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, rateA was considered for Winter, rateB for Summer and rateC was not taken into consideration. For transformers, rateA was considered as unique rate, thus rateB and rateC were not taken into consideration. The tolerance considered for overload was 0% for all branches, in N and N-1 situations.

Regarding the loss of generating units, the energy lost was compensated by controlling the interconnection with FYROM.

Finally, a set of N-2 outages has been specified for the project GRCYIS:

bus FROM	bus TO	IC	bus FROM	bus TO	IC
GACARN11 400.00	GKOUMO11 400.00	1	GKOUMO11 400.00	GK_KOR12 400.00	1
GKOUMO11 400.00	GKYTROUF12 400.00	1	GK_KOR12 400.00	GK_KORK11 400.00	1
GKROUF11 400.00	GKYTROUF12 400.00	1	GKOUMO11 400.00	GK_KOR11 400.00	1
GACARN11 400.00	GKOUMO11 400.00	1	GK_KOR11 400.00	GK_KORK11 400.00	1
GACARN11 400.00	GK.ROUF13 400.00	1	GK_MEG15 400.00	GKMEG14 400.00	1
GKROUF11 400.00	GK.ROUF13 400.00	1	GK_KOR13 400.00	GKMEG14 400.00	1
GACARN11 400.00	GAG.ST11 400.00	1	GK_KOR13 400.00	GK_KORK11 400.00	1
GACARN11 400.00	GAG.ST11 400.00	2	GK_MEG15 400.00	GKMEG12 400.00	1
GK_LAR11 400.00	GACARN11 400.00	1	GK_KOR14 400.00	GKMEG12 400.00	1
GK_LAR11 400.00	GACARN11 400.00	2	GK_KOR14 400.00	GK_KORK11 400.00	1
GKOUMO11 400.00	G_HERON11 400.00	1	GK_NSA11 400.00	GFILIP11 400.00	1
GHERON11 400.00	G_HERON11 400.00	1	GK_NSA11 400.00	GFILIP11 400.00	2
GKOUMO11 400.00	G_THISV12 400.00	1	GFILIP11 400.00	GKLAG11 400.00	1
GTHISV11 400.00	G_THISV12 400.00	1	GFILIP11 400.00	GKLAG11 400.00	2
GDISTO13 400.00	G_HERON12 400.00	1	GKYT_T11 400.00	GKLAG11 400.00	1
GHERON11 400.00	G_HERON12 400.00	1	GKYT_T11 400.00	GKLAG11 400.00	2
GDISTO13 400.00	GTHI13 400.00	1	GKLAG11 400.00	GAMYNT11 400.00	1
GTHISV11 400.00	GTHI13 400.00	1	GKLAG11 400.00	GAMYNT11 400.00	2
GKYT_T11 400.00	GAGDI12 400.00	1	GPTOLEM 400.00	GAMYNT11 400.00	1
GKYT_T11 400.00	GAGDI12 400.00	2	GPTOLEM 400.00	GAMYNT11 400.00	2

Table 5 – N-2 outages considered for the Greek system in project GRCYIS

Cyprus

For the system of Cyprus, the highest voltage level is 132 kV. Therefore, the N-1 was focused on that level. The branches considered for the N-1 analysis but also as the monitored elements were only those at 132 kV.

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

Regarding the loss of generating units, the energy lost was compensated internally, using ancillary services of the rest of Cyprus generating units.

Finally, a set of N-2 outages has been specified by combining the outage of the main or alternative interconnections between the three power stations of Cyprus system (Vassilikos, Alambra and Dhekelia), i.e. the backbone of the Cyprus system.

5 Assessment of reinforcements

The main outcomes of the contingency analysis for each system involved in the Project could be summarized to the following:

Greece

All overloadings observed are not considered critical and can be resolved by generation redispatch, thus no internal reinforcements are needed in the Greek System.

Cyprus

Taking into account the approved Cyprus Ten Year Network Development Plan 2018-2027, no additional internal reinforcements were identified in the Cyprus System with respect to the GRCYIS project.

Next figure shows the map of the projected interconnection (yellow line).

Figure 1 – Map of interconnections and reinforcements for project GRCYIS

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 tables show the active power losses summary for each of the PiTs, **Errore. L'origine riferimento non è stata trovata.** with the results for the Greek system and **Errore. L'origine riferimento non è stata trovata.** with the results for the Cyprus system.

	Power losses [MW]		
PiT	Without proj&reinf	With proj&reinf	Difference (W-WO)
4	166.9	167.0	0.0
5	153.0	160.0	7.0

Table 6 – Comparison of the active power losses for each snapshot, with and without interconnection projects and reinforcements, for the Greek system

	Power losses [MW]		
PiT	Without proj&reinf	With proj&reinf	Difference (W-WO)
4	10.9	9.4	-1.5
5	17.3	9.4	-7.9

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

Based on the above calculation, PiT5 was excluded as non-representative for the calculation of internal losses, since it represents a very small time percentile of the relevant scenario and it results in reduction of losses around 45% of the total losses in the Cyprus System which is not realistic.

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 2 scenarios examined. The following table shows the annual internal delta losses estimate for each system, as well as the total annual internal losses:

Scenario	Annual Internal Losses (MWh)		
	GR	CY	Total
S3	258	-13,372	-13,114
S4	258	-13,372	-13,114

Table 8 – Annual internal delta losses estimate for each country

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 2 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 S3 and S4 and 8760 hours of estimated flows through the interconnections. The following table shows the annual losses estimate on the interconnection project for each scenario:

Scenario	Annual Losses on Interconnection (MWh)		
	GR-CY	CY-IS	Total
S3	1,067,210	345,621	1,412,831
S4	1,032,149	360,772	1,392,920

Table 10 – Annual losses estimate for the new GRCYIS 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 each country, 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€)
	GR			CY					
	Interconnection	System	Total	Interconnection	System	Total			
S3	31.94	0.02	31.95	42.28	-0.80	41.48	**74.22**	**-0.78**	**73.43**
S4	40.05	0.02	40.07	54.05	-1.04	53.01	**94.09**	**-1.02**	**93.08**

Table 81 – Annual cost of losses estimate for the new GRCYIS interconnection

As a general remark, apart from the losses on the HVDC interconnection the project results in a negligible increase of the internal losses in Greece and a small decrease in Cyprus.

7 Estimation of Investment Cost

The new HVDC link between Greece, Cyprus and Israel will 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.

It should be further stressed that the routing of the link crosses very deep waters between Greece and Crete but mostly between Crete and Cyprus, where the maximum depth is more than 2km which is reported as the limit of the technologies currently implemented, thus constituting this project particularly challenging to this respect.

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.

P14 - GRCYIS - Investment Cost								
New Interconnections								
Description	**Type**	**Countries Involved**	**Length/number**		**Total Investment Cost**	**GTC Contribution**	**Location**	**Status**
			OHL [km]	**Cable [km]**	**M€**	**MW**		
1st Stage New interconnection Greece-Cyprus- Israel 1000MW	HVDC Submarine Cable	GR		335	3590	1000	S-E GR (Koumoundouros) - C Crete (Damasta)	Mid-term
	HVDC Underground Cable	GR		37			S-E GR (Koumoundouros) - C Crete (Damasta)	Mid-term
	HVDC Converter Station	GR		1			C Crete (Damasta)	Mid-term
	HVDC Submarine Cable	GR - CY		896			C Crete - CY (Alaminos)	Mid-term
	HVDC Underground Cable	GR - CY		18			C Crete - CY (Alaminos)	Mid-term
	HVDC Converter Station	CY		1			CY (Kofinou)	Mid-term
	HVDC Submarine Cable	CY - IS		310			CY (Vassilikos) - IS (Hadera)	Mid-term
	HVDC Underground Cable	CY - IS		13			CY (Vassilikos) - IS (Hadera)	Mid-term
	HVDC Converter Station	IS		1			IS (Hadera)	Mid-term
2nd Stage New interconnection Greece-Cyprus- Israel 1000MW	HVDC Submarine Cable	GR		333	2362	1000	S-E GR (Koumoundouros) - C Crete (Damasta)	Mid-term
	HVDC Underground Cable	GR		37			S-E GR (Koumoundouros) - C Crete (Damasta)	Mid-term
	HVDC Submarine Cable	GR - CY		894			C Crete - CY (Alaminos)	Mid-term
	HVDC Underground Cable	GR - CY		18			C Crete - CY (Alaminos)	Mid-term
	HVDC Submarine Cable	CY - IS		333			CY (Vassilikos) - IS (Hadera)	Mid-term
	HVDC Underground Cable	CY - IS		13			CY (Vassilikos) - IS (Hadera)	Mid-term
Total Cost of New Interconnections (M€ / %total)					**5952**	**100%**		
Internal Reinforcements								
Description	**Type**	**Countries Involved**	**Length/number**		**Total Investment Cost**	**Capacity**	**Location**	**Status**
			OHL [km]	**Cable [km]**	**M€**	**MW / MVA**		
No Internal reinforcments required								
Total Cost of Internal Reinforcements (M€ / %total)					**0**	**0%**		
Total Project Investment Cost					**5952**			

Table 9 – Investment costs of the project GRCYIS

Assessment results for the Cluster P14 - GRCYIS														
non scenario	GTC increase direction 1 (MW)		2000											
	GTC increase direction 2 (MW)		2000											
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)		GR	3462	5462	2000	3462	5462	2000	3462	5462	2000	3462	5462	2000
		CY	0	2000	2000	0	2000	2000	0	2000	2000	0	2000	2000
		IS	0	2000	2000	0	2000	2000	0	2000	2000	0	2000	2000
Interconnection Rate (%)*		GR	14.4%	22.7%	8.3%	17.8%	28.1%	10.3%	13.0%	20.5%	7.5%	10.6%	16.7%	6.1%
		CY	0.0%	86.2%	86.2%	0.0%	76.2%	76.2%	0.0%	88.9%	88.9%	0.0%	75.9%	75.9%
		IS	0.0%	10.9%	10.9%	0.0%	10.9%	10.9%	0.0%	10.9%	10.9%	0.0%	10.9%	10.9%
Benefit Indicators	B1-SEW	(M€/y)								710			480	
	B2-RES	(GWh/y)								190			1000	
	B3-CO_2	(kT/y)								-3600			2100	
	B4 - Losses	(M€/y)								93.4			114.7	
		(GWh/y)								1400			1380	
	B5a-SoS Adequacy	(MWh/y)								21000			32000	
	B5b-SoS System Stability													
Residual Impact Indicators	S1- Environmental Impact													
	S2-Social Impact													
	S3-Other Impact**													
Costs	C1-Estimated Costs	(M€)									5952			

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

** contribution to EU energy targets: the project marks the end of the energy isolation of Cyprus, last member of EU remaining fully isolated without any electricity or gas interconnecti

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 10 – Results of the Cost Benefit Analysis for the GRCYIS project

8 References

1	Snapshots building process	Share point
2	Guide for setting up grid models for Network studies V 5.0	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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