Turkey - Romania Subsea Transmission Cable Investment: Time for Reconsideration?

Burak Güler[1] Emre Çelebi[2]

David Fuller[1] Jatin Nathwani[1]

[1]Dept. of Management Sciences
University of Waterloo
Waterloo, ON, Canada, N2L 3G1
bguler@uwaterloo.ca

[2]Dept. of Industrial Engineering
Kadir Has University,
Istanbul, Turkey, 34083

***Abstract*— Transmission investment is important for integrating electricity markets operated by different countries/transmission system operators (TSOs). Turkey and Romania have proposed a transmission cable linking the transmission network between two countries under the Black Sea, but this investment has been found infeasible due to the insufficient technical and financial benefits to the countries/TSOs. Now, there may be a case for revisiting this project given emerging national and global policy frameworks leading to a "shadow price" for carbon requiring decision analysis for investments to be guided by an explicit accounting of carbon-constraints. We propose a method that estimates the overall net benefit investing in this project by evaluating the project from the following perspectives: (1) economics where the energy resources of both countries are better utilized by evaluating the electricity supply and demand of each country (2) financial where the additional access to European electricity markets brings more trades in when the two promising markets are physically coupled (3) environmental where the effect of emission constraints are introduced.**

***Index Terms*-- transmission investment, emissions, electricity markets, social welfare.**

I. Introduction

Turkey is strategically located between Europe and the Middle East and Asia to position itself as a regional energy hub, but also geographically support its role as a regional energy corridor or bridge. As most of the world`s top producers of oil and gas located in the Middle East: Iran, Iraq, Azerbaijan, Saudi Arabia are within close reach of Turkey`s borders or neighbor's borders. Turkey is also a strategic neighbor to top consumers of European Union countries in the West of its borders: Bulgaria, Greece and Romania, accessing to the south east Europe and to the central Europe.

The Climate change and its consequence to reduce GHG emissions around the world have been recognized by the governments for years. Moreover, the industry has also recognized it and started taking action towards it. Hence, concepts such as low-carbon economy or low-carbon energy market, low-carbon growth have been adapted by the industry and the governments together to better manage the transition into this new era whether by switching to renewable energies or implementing energy efficiency measures, etc.

As shown in Figure 1, Turkey is in a unique position, corridor or bridge role to connect the Middle East and Europe and its Energy exchanges while exploring the options for low-carbon growth during this transition period. This position creates opportunities for Turkey and its neighboring countries to explore regional energy hub strategies for transition to low carbon economy. The success of this transition to low carbon energy economy depends on creating regional energy hubs.

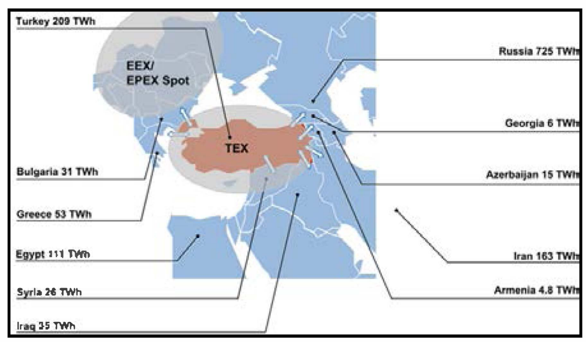

Figure 1. Turkey and the neighboring countries in transition to low carbon economy [1]

II. The Challenge

Regional energy hubs are created solely on the basis of the merchant transmission investment to tap into the electricity price differences between the markets and to create a strategic interconnection capability between the countries.

Greenhouse Gas (GHG) emissions produced in an electricity generation sector of a country or a market should also be considered in creating a regional energy hub due to its effect on the electricity pricing rising from the carbon tax, which is considered around the world to make the transition into low-carbon economy. A carbon tax is a tax on energy sources which emit carbon dioxide and consequently pollutes the environment.

A country or a market considering a carbon tax due to carbon based electricity generation mix (Coal, natural gas) should be interested in exploring strategies for the creation of regional energy hubs with the neighboring markets to make the transition to low carbon economy.

It is clear that in order to make the transition into low-carbon energy economy a success, regional energy hubs now should be considered even more taking into account the effect of GHG emissions, and the carbon tax.

III. THE LITERATURE REVIEW ABOUT THE CHALLENGE

The current literature review suggests that the regional energy hubs are only considered and prioritized from the merchant transmission investment, arbitrage opportunities between the markets and interconnection capabilities to match the supply and demand, and in one instant create a single energy market. It is partially considering the effect of the GHG emissions produced by a country and its consequence of upcoming carbon tax in planning of the generation, and its ultimate effect on the electricity prices.

It is EU`s objective to create a single energy market by integrating regional energy initiatives as set below. CEER`s priority in regional energy initiatives are interconnection capacity, congestion management, balancing and transparency to name a few. It does not take into account the GHG emissions and carbon tax in generation planning.

Another example, a feasibility study regarding a subsea cable between Romania and Turkey had been completed by ABB in 2004. However, the project had never been completed due to not economically being feasible - only considering including market price differences. However, it could turn out that this project may be one of the projects to support the transition to low carbon energy economy in the region as well. Figure 2 shows the 1000 MW subsea transmission line connecting Romania to Turkey.

Figure 2. Romania-Turkey Subsea Cable [2]

The argument is that in transition to low carbon energy economy, some of these initiatives should be reconsidered to include the effect of carbon tax coming from electric generation in the specific market or a country and its effect on the electricity prices in the region.

Figure 4 shows the regional view in relating to the Turkish-Romanian undersea cable to the research question of creating regional energy hubs for transition to low carbon energy economy.

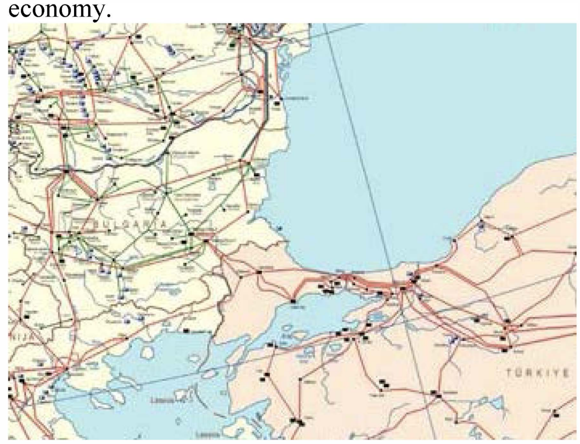

Figure 3. The region in question to create a regional energy hub. Turkey, Romania, Bulgaria, and Greece [3]

IV. THE RESEARCH QUESTION

The motivation of this research is to identify regional energy hub strategies for transition to low carbon energy economy, and some of the motivation can be laid out are as follows:

• To reduce the overall GHG emissions for the geographic region that is nearby as shown in Figure 3.
• To better utilize energy across the region to compensate for the growing demand,
• To increase the power (energy) trading among countries, hence the increase of Social Welfare,
• To establish a single price for the region, now it is different for every country.
• Physical energy (commodity) connection - Transmission, pipeline, or a LNG terminal,
• Ultimately to establish a working energy market -

But the real research question that needs to be answered is as follows:

• Do we have enough transmission capacity to serve the needs identified above?
• We think that it is not enough, and there are projects that are abandoned or not realized due to their infeasibility Turkey-Romania Undersea cable.

To support the overarching research question laid out above, the objective of this study is to determine whether it is better to invest in Transmission capacity to:

- utilize energy in the region,
- reduce the GHG emissions,
- nudge investors more towards non-GHG polluting technologies,
- create a regional hub that serves the region.

V. THE METHOD

The Figure 4 below shows the method considered taking into account in converting strategies into meaningful outcome where the process starts with the data input required for the model, the data is inputted into the linear programming model, and with this model several scenarios are compared and evaluated to show the requirement for a transmission investment.

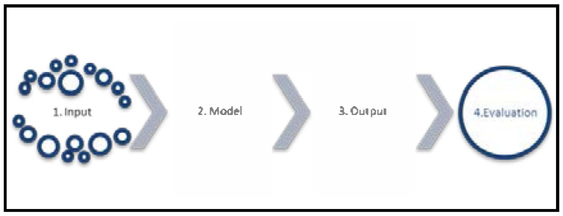

Figure 4. The Method

The most important part of the input is the preparation of the data set. The data set has been divided in to two major parts: generation and transmission data sets, where two of the sets have been retrieved and assumed directly from [4] to make the data set work well with the conceptual study of the proposed idea. Section 5.1 below gives details on the data set and assumptions. Also Figure 5 shows the visual description of the proposed research question indicating the transmission line connections between the hubs, etc. For this study, the import and export related activities have not been considered. It is assumed that for a realistic study, ımport and export studies should be part of the data set.

5.1 Input Data sets for Generation and Transmission

Table 1. Generation Related Data Set

Total Parameters at the Bus	Min Power Output (MW)	Ins. Cap. 2010 (MW)	Gen. (MW)	Gen. Cost ($/MWh)	Demand (MW)	Unserved Energy Cost ($/MWh)	GHG Emiss (t/MWh)
Bulgaria. Bus #1	1000	10,176	5,103	54.5	4,132	56	0.492
Turkey. Bus #2	1500	49,562	22,991	62.9	22,900	80	0.584
Greece. Bus #3	500	16,729	6,107	64	6,758	85	0.887
Romania. Bus #4	300	16,460	6,016	57.4	5776	58	0.426

Assumptions and data sources generating the Table above:

Minimum power output requirement is assumed from [4] Installed Capacity Data, Generation, Demand [5] for power has been retrieved from each country`s regulatory bodies as a principle. Generation cost is calculated as follow based on each country´s fuel mix. Unserved energy cost data is taken from [4]. GHG emissions data are taken [7].

Table 2. Transmission Line Related Data Set [4]

Line #	From Bus #	To Bus #	Susceptances (S)	Capacity (MW)
1	1	2	100	500
2	1	3	125	800
3	2	3	150	500
4	1	4	150	500
5	2	5	150	500

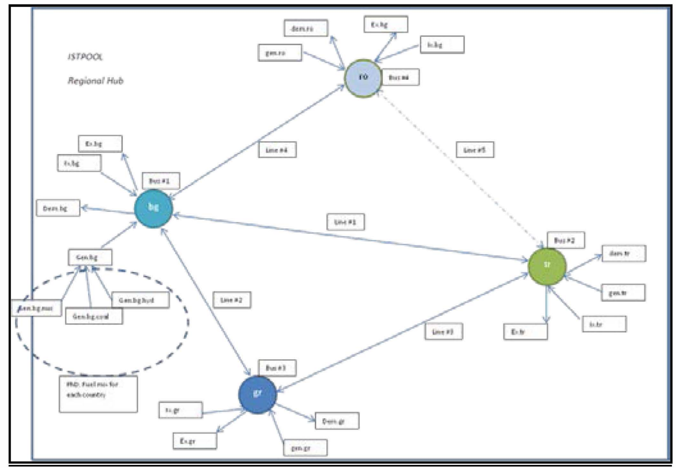

Figure 5. The Regional Hub Model of Turkey, Bulgaria, Greece, and Romania.

5.2 The Generic Mathematical Model

Linear programming (LP) model is based on minimizing total cost and is given below. The overall methodology and approach has been applied from [4], and the mathematical is available therein. The model is coded in GAMS and solved by the CPLEX solver.

Min Total Cost = Generation Cost + Energy Cost

s.t.

I. Energy Balance at the bus level
II. Flow Equations for the Existing Line
o Reference Bus
IV. Min Power output and Capacity of power output
V. Positive energy and Demand
VI. Line Capacity Limits for the Existing Lines
VII. Emission Constraints: Generation based

5.3 *Output: Scenario Analysis*

Table 1.The Output of the Mathematical Model– Decision Alternatives versus the Nature of the States.

Decision Alternatives:	**No Emissions**	**Emissions**
No Line. Model A	Generation Cost for each Country: BG,TR,RO,GR	Generation Cost for each Country: BG,TR,RO,GR
	Total Generation Cost for the Regional Hub	Total Generation Cost for the Regional Hub
Line. Model B	Generation Cost for each Country: BG,TR,RO,GR	Generation Cost for each Country: BG,TR,RO,GR
	Total Generation Cost for the Regional Hub	Total Generation Cost for the Regional Hub

Based on the above table, the following results regarding the total cost generation will be produced utilizing the generic mathematical model given above in Section 5.2 by utilizing the following scenarios and the corresponding constraints:

• Base Case. No line + no emissions: In the GAMS code, the no new line information and the emission constraints are applied.

• Scenario 1. No Line + emissions: In the GAMS code, only the emission constraint is applied.

• Scenario 2. Line + no emissions: In the GAMS code, the new line information is applied without the emission constraint.

• Scenario 3. Line + emissions: In the GAMS code, the new line information as well as the emission constraint is applied.

5.4 Evaluation of the Overall Results

After receiving the results from the model output completed in Section 5.3, the following approach will be completed in order to see the appropriateness of the investment approach,

a. Evaluate and record the generation cost differences among all the scenarios outlined above and see the impact of the line and the emission differences, and

b. Compare this information with the investment amount required to build a line between Turkey and Romania.

VI. THE EVALUATION OF THE OVERALL RESULTS FOR TOTAL COST

The results of the GAMS that was run for the above scenario analysis are tabulated in Table 1 below. The more results about the actual flow, change in the generation and unnerved energy are in Section 11. Table 1 shows the bottom line net benefit of the scenario analysis from the total cost perspective.

The results show that there are savings when the line (TR-RO) implemented with emissions constraints. This is the difference between Base Case (no line and no emissions) and Scenario 3 (line implementation and with emissions), which is:

- Total Cost difference between:
- Base Case - Scenario 3 = 25,877.818 – 25,851.835 $ = 25.983 (hundred dollars)

which is about 2600 $ per hour savings with the implementation of 500 MW (i.e., it will be about 5$/MWh savings) line between Romania and Turkey to create a regional hub. The above scenario is applied for the comparison of both line implementation and emission constraint. To conclude, there is a net financial benefit in implementing the line with emission constraints.

VII. THE EVALUATION OF THE OVERALL RESULTS FOR TRANSMISSION INVESTMENT

Technical and economic assumptions are derived from Transelectrica to make a comparison with the findings from Section 6 and the actual investment figure assumptions are given below.

- Cable Capacity: 500 MW
- Construction time: 3 years
- Cable Cost: 500 million $
- Transmitted Energy per year ~ 4.0 TWh as per 8000 hr availability.
- Marginal generation price in TR 63 $/MWh
- Marginal Generation Price in RO 57.5 $/MWh
- Price arbitrage: 5.5 $/MWh * 4 000 000 MWh = 22 million $. Net Financial gain for one year contract.
- Cost saving: 5 $ /MWh is the saving from line and emission consraints for the new line. * 4 000 000 MWh = 20 000 000 $. Net savings of $ investing in a transmission line.
- Total Benefit: 22 Million + 20 Million= 42 million $
- Simple Pay Back: 500 Million $ / 42 Million $ = 11 years.

VIII. CONLUSION AND THE RECOMMENDATION

Total cost minimization approach has estimated the net benefit of a transmission line. With the implementation of a new transmission line between Romania and Turkey the regional energy hub strategies will help the region in transition to low carbon energy economy faster. This illustration has shown that there are potential benefits of regional energy hub from the following perspectives:

- Lower prices in the region
- Investments and the economic growth
- Reduce environmental impact in the region and help each country meet the Kyoto requirements.

This paper has illustrated that the concept of regional energy hubs with additional transmission line capacity considering emission constraints. However, the proper assessment of a real world application needs to be extended to include realistic data set and its preparation for the generation, line susceptances, line usage tariffs and line limits, and the model should be run for all hours of a typical year.

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