A Proposal for the Integration of the Energy Matrix from a Graph Theory Perspective

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Abstract

Brazil has stood out as a major producer of renewable energy in the world, despite advances in terms of its use, it is not yet a potential collaborative generator due to the inability of a bidirectional flow over the existing energy matrix, which has, in its extension, a strong limitation from the topological point of view, therefore, looking for computational models that operate within optimal solutions, supported by Graph Theory, is the objective of this work, making use of the Kruskal and Vertex Cover algorithms. to identify an alternative capable of producing a usable scenario under the implementation aspect and with a reduction of the costs under this expansion.

Keywords: Graph Theory; algorithms; energy matrix; networks;

1. Introduction

The existing technological advances caused by the digitalization of communication models in the world are undeniable, and the current relationships have been consolidated in a bidirectional process in the flow of information, so that the agents involved in this relationship can establish a mutual model of contribution, ensuring a new perspective in the use of services supported by the so-called "digital world".

This "digital world", defended by Lévy (1999, p.29) some years ago as collaborative, stating that "the support of collective intelligence is one of the one of the main conditions of its own development", brought to this development an extrapolation of the technical barriers of computational expertise, and technology today, used through computer resources, has unleashed contribution models in various segments of society, such ramifications technological ramifications have brought gains and losses, but the fact is that these innovations unleashed research possibilities that, until then, its construction process was unimaginable.

This need continues for an increasingly connected world, some sectors of society have become a base of support for the continuity of this technological reality, among them, we can mention the energy sector, which brings in the epistemology of the word, a strong relationship with movement. The design between the movement capacity of the data flows generated from the computational technological elements and the energy flow generated over an energy matrix such as that of brazil, converge within the same transmissibility model that can be represented graphically, highlighting the neighborhoodrelations in a way analogous to the point-to-point links between routers in a computer network for the representation of a given path. Based on the need to guarantee a model that aims at the expansion of the existing energy matrix in Brazil,highlighting the guiding elements that sustain the National Energy Plan (PNE) 20501[1], this paper aims at proposing a model for decentralized and interconnected distribution, having as research locus the State of Bahia, without disregarding the specificities of each region on the renewable energy potential of each municipality, making use of an optimal model on the cost of implementing production concentrators for municipality, making use of an optimal model on the cost of implementing production concentrators for the 417 (four hundred and seventeen) municipalities in the State of Bahia.

Given the above, the insertion of a computational model that allows the use of graphs to obtain these interconnection results is a path to be explored, thus, in section 2, it will be highlighted the similarities and differences between the two scenarios in networks, through an approximation of graph concepts. In section 3, the challenges proposed in the PNE 2050 are identified from the point of view of the expansion of the electric matrix in Brazil, considering the costs of implementing an infrastructure that serves a larger coverage area, in order to guarantee the availability of access to the population. In section 4, the methodology of the transition process between the elements belonging to the scenario presented will be presented, for a computational model, aiming at the minimum use of substation implementation resources for the use of optimal paths on the flow generated in an energy matrix with its results and, finally, in section 5, the final considerations about the work will be presented.

2. A Networked World

When we talk about the word "networks", it is common to establish a direct relationship with the internet, this approach has a connection with the transformation generated by the notorious success that the network - internet - has produced in the way we relate today, but this concept of networks comes from many years ago, more precisely in 1735, when the Swiss mathematician Leonard Euler faced the challenge of the seven bridges of Königsberg, thus giving rise to the Graph Theory.

A graph corresponds to a mathematical abstraction defined, according to Feofiloff et al. (2011), in an unordered pair, determined by (V,A), where "V" corresponds to a set called vertices and "A" a set called edges, where the edges of the set "A" impinge on the elements of the arbitrary set "V", forming a relationship. This mathematical model that establishes pairwise relationships between the vertices of its set through the edges, triggered several possibilities making use of several algorithms, thus bringing computing closer to this area.

This approach, corroborating with Wilson (1996) when relating the Graph Theory as a mathematical tool

[1] https://www.epe.gov.br/pt/publicacoes-dados-abertos/publicacoes/Plano-Nacional-de-Energia-2050

that acts in various areas of knowledge and, when considering the various representations that a graph can taking as an example a computer network, we define in an analogous way, the vertices of a graph as the routers responsible for routing the flow of data routing the flow of data generated by its various users, thus establishing a pair relationship over each hop that this data packet makes in the network until its final destination, through a path between source and destination.

The scenario about the topology that characterizes this relationship was to seek the existing concepts about graphs in which would be these best paths, in order to optimize this communication, for this, several algorithms based on graphs were used, among them, Dikjstra's algorithm is used, which calculates the lowest cost, or minimum path, between two vertices of a graph, considering there a relation of valuation on the existing paths.

In this sense, it is possible to establish a close relationship with the electric power sector, since the flow of the energy matrix is constituted by a network of connections supported by a concentrator, or power plant, with the capacity to send energy to certain locations and whose routing process takes place through "access keys" that determine the path to be taken.

Unlike the model adopted in computer networks, where the automated process of reconstructing the paths that a data packet in the network can, in just seconds, decide to take in case of a failure, in energy matrices this process does not happen in the same way, causing in the interval between the beginning of the failure and the availability of the service again, not only financial losses for both parties - consumer and producer - as well as the possibility of irreparable losses, especially in the health area.

Another important element within the context of bidirectionality is the ability to establish, always, a path between any vertices of a graph, this feature in Graph Theory characterized by a connected graph, is a challenge to be explored but it does not mean, necessarily, a single raw material for energy production, thus, it would be possible to explore all the capacity of using the various existing renewable sources, especially in Brazil, in an integrated manner, ensuring the ability to establish a collaborative relationship between the elements that make up this model.

Also in order to consider a lower cost on the need for transmission paths over the various regions of Brazil,it would be possible to establish through the shortest path algorithm, inserting there the concept of trees of optimal paths, which in Graph Theory corresponds to any subgraph that connects all vertices of a graph without the establishment of cycles, that is, a relation where some vertex on the flow of origin and destination meet at some point, considering the lowest costs or weights of each relation of this graph, it would be possible to establish a reduction on the need for communication between all vertices of this network.

It is worth remembering that the communication process, not only in computer networks, but also in the energy matrix, requires a solution that ensures the ability to reuse alternative paths due to the momentary lack of interoperability of some device, a characteristic that, in the scope of computer networks is known as redundancy, and that extends to the area of electric power.

It is a fact that challenges are posed all the time about the demands that the energy sector has to integrate an entire existing energy matrix, but some of these situations can be answered with the help of Graph Theory, bringing elements that dialogue with the future prospects of a connected world and the gains that this scenario can produce for society, relating the conceptual aspects existing in the Graph Theory with the demands proposed by the PNE 2050.

3. What to Expect of the Energy Future Under the Eye of the PNE 2050

The social state which, according to Bonavides (2007, p.200), constitutes a:

"The interventionist state, which always requires the militant presence of political power in the social sphere, where the dependence of the individual has grown, because of the impossibility in which he finds himself, due to factors beyond his control, to provide certain minimum existential minimum existential needs".

The energy production capacity of a country has a strong connection with the communities' state of social welfare, this relationship dialogues with several sectors of society, such as: Education, Health, Economy, among others; in this sense, just like the internet, which has consolidated itself as an inexhaustible source of indispensable information to minimize the impacts of a notorious social inequality, among other things, energy, which also enables the capacity to provide this technological resource, constitutes a fundamental element for human survival.

In view of this social need, the PNE brings in its report, a set of guidelines that direct improvements in the Brazilian energy sector with the aim of ensuring the supply of energy through hydroelectric expansion for the whole country, making use of a transmission network that ensures, for the whole society, a supply of energy capable of meeting the growing demand for electricity in Brazil.

In this sense, from a perspective of expansion of this energy matrix, some recommendations of the PNE are highlighted within this process aiming not only at the expansion of this network, but also at the ability to provide a greater digitalization of energy production in the country. This insertion of information and communication technologies in the production and use of electricity in the country brings several inseparable elements, among them, the connectivity between peers, as a way to ensure all the digital potential that a model with these characteristics has.

This possibility of transforming an analog model to a digital model produces results in several layers in this relationship between consumer and producer, including allowing an alternation of position, so that, attimes, this consumer can, in case of local energy production capacity, return to the grid an overload of generated production not consumed, known as prosumer, adding to this possibility, a reduction in the costof the tariff and/or marketing of this local production.

This possibility also dialogues with elements that influence the production of renewable energy, taking advantage of all the existing potential in the country, thus fomenting, in these alternative renewable sources, the possibility of generating new business, as well as, actively acting in the reduction of greenhouse gas emissions and non-renewable elements that contribute to an increase in threats from climate change caused by the burning of fossil fuels for energy generation.

The digital transformation, resulting from this whole digitalization process, will provide, from the elements that act within a digital model, the ability to provide intelligence on all the processes that affect this model, making it possible to establish a set of businesses capable of causing several changes, acting in generation, transformation, distribution, and consumption.

Another element highlighted in the PNE and that acts within a context of transversality, is the ability to decentralize the large production hubs, since many communities can be served from local energy producing sources in case of unavailability, in this sense, it is possible to establish a stimulus policy for certain regions that have a privileged location in relation to neighborhood over other regions, thus establishing a scenarioof sharing between peers from the characteristics of a model of connectivity on existing relationships, mentioned earlier.

4. Methodology of the Transition Process on Connectivity in the Energy Matrix

Facing a scenario of complexity about the characteristics that affect a matrix with these dimensions and regional particularities, aiming to establish a minimum use of implementation resources on the energy producers, considering the existing costs in the construction of substations that feed this matrix, as well as, the determination of a transmission line for all the existing energy demand, some elements can be brought from existing computational models aiming at the use of optimal paths and vertex coverage on the flow generated in an energy matrix.

This perspective of scenario building acting under a computational reading, expands the discussions about the use of optimal models through the implementation of algorithms that, from the indication of reference criteria about their implementation, will establish results compatible with a technical reading, although not necessarily representing a local reality in function of the several characteristics that occur within an energy production perspective, but that, by directing to criteria that act directly within the specific contexts, may bring better results from the decision making point of view.

Thus, for a reading about the relations (which from now on we will call only edges) between the vertices (which from now on we will call only nodes) of the graph (which from now on we will call only network),a network will be built considering the use of the cost element (which from now on we will call only distance) identified on the existing distance between the nodes, which will be represented by each territory of Bahia, through an optimal model based on the use of Minimum Generation Trees (which from now on we will call backbone), from a mathematical representation about the existing edges that will act in this backbone, forming the network of territories of Bahia, as a support for possible new cost criteria on these edges.

Still on the minimum use of energy producers, it is also possible to establish a link with the vertex cover algorithm to identify all the edges of the network that fall on the fewest number of nodes in the network, so that all the edges in the network have at least one edge associated with a node, thus reducing the need for energy production on all the nodes that fall on the map representation of the network.

As the objective of the proposed model is not to explore the time complexity of the algorithms that will be used, but to present a valid and optimal proposal for the creation of a backbone with vertex cover, considering the shortest distance between each edge for the construction of the network, according to the concept mentioned in section 2 (two), two moments of application on the computational models will be used to obtain the results for a better presentation of the results.

4.1 A Modeling from the Edges of the Network

Kruskal's algorithm, which consists of including the edges that have the shortest distance in the network to form the backbone, at the end of the process, will produce the best path, forming a transmission network that includes all the regions identified in this shortest path, from the distance between the territories, thus forming the network backbone.

As the identification of the distance in the construction of the network, considering the map by territory of identity, is not possible due to the composition of the various municipalities in each territory of Bahia, the municipality that, within its respective territory, has the highest Gross Domestic Product (GDP)[2], Table 1, was adopted as a reference for the distance between the territories.

Table 1. The Municipalities with the largest share in GDP in the Bahia Territories in 2018.

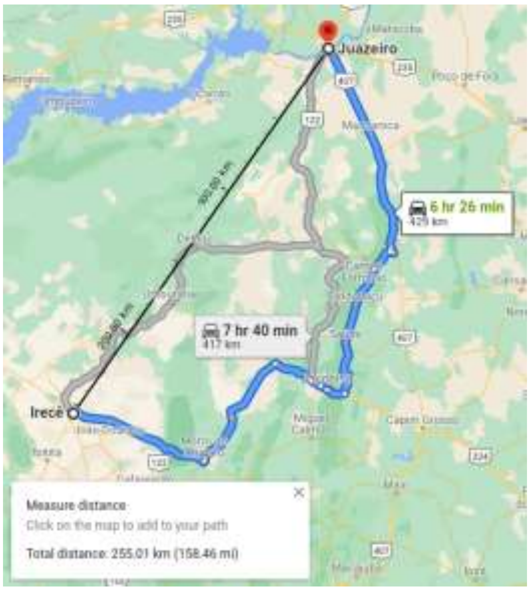
Code	Identity Territory	Municipality with the largest GDP	Latitude	Longitude
1	Irecê	Irecê	-11.3	-41.85
2	Velho Chico	Bom Jesus da Lapa	-13.25	-43.41
3	Chapada Diamantina	Seabra	-12.41	-41.77
4	Sisal	Serrinha	-11.66	-39.00
5	Litoral Sul	Ilhéus	-14.78	-39.04
6	Baixo Sul	Valença	-13.36	-39.07
7	Extremo Sul	Teixeira de Freitas	-17.53	-39.74
8	Médio Sudoeste da Bahia	Itapetinga	-15.24	-40.24
9	Vale do Jiquiriçá	Maracás	-13.44	-40.43
10	Sertão do São Francisco	Juazeiro	-9.41	-40.5
11	Bacia do Rio Grande	Luís Eduardo Magalhães	-12.09	-45.8
12	Bacia do Paramirim	Macaúbas	-13.01	-42.69
13	Sertão Produtivo	Brumado	-14.2	-41.66
14	Piemonte do Paraguaçu	Itaberaba	-12.52	-40.3
15	Bacia do Jacuípe	Ipirá	-12.15	-39.73
16	Piemonte da Diamantina	Jacobina	-11.18	-40.51
17	Semiárido Nordeste II	Ribeira do Pombal	-10.83	-38.53
18	Litoral Norte e Agreste Baiano	Alagoinhas	-12.13	-38.41
19	Portal do Sertão	Feira de Santana	-12.26	-38.96
20	Sudoeste Baiano	Vitória da Conquista	-14.86	-40.83
21	Recôncavo	Santo Antônio de Jesus	-12.96	-39.26
22	Médio Rio de Contas	Jequié	-13.85	-40.08
23	Bacia do Rio Corrente	Correntina	-13.34	-44.63
24	Itaparica	Paulo Afonso	-9.4	-38.22
25	Piemonte Norte do Itapicuru	Campo Formoso	-10.5	-40.32
26	Metropolitano de Salvador	Salvador	-12.97	-38.51
27	Costa do Descobrimento	Porto Seguro	-16.45	-39.06

[2] https://www.sei.ba.gov.br/index.php?option=com_content&view=article&id=2289&Itemid=265

The choice of the GDP, which, according to IBGE[3], is defined as the sum of all final goods and services produced by a country, state, or city", thus characterizing, still according to IBGE, as an "indicator of the flow of new final goods and services produced during a period", constitutes an indicator with productive potential for the installation of plants in each territory.

To identify the distances between the existing neighborhoods of the territories represented by their respective municipalities that make up the edges of the network, Google Maps was used, as it is a consolidated technological platform widely used in estimating the distance between two points in the world, with results obtained from the identification of the municipalities, Figure 1, to calculate the distance.

Figure 1. Distance between two municipalities (Irecê x Juazeiro)



Source: Google Maps

Based on the elements presented, considering the distance from the neighbors, Figure 2 transports the map of the Identity Territories[4] to the graphic representation that will act in the construction of algorithms that focus on the research objective, bringing a better view of the neighborhood relations existing in the previously defined locus.

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[3] https://www.ibge.gov.br/explica/pib.php

[4] http://www.seplan.ba.gov.br/modules/conteudo/conteudo.php?conteudo=17

Figure 2: Graphic representation of the network about the Identity Territories in the State of Bahia

Source: Adapted from SEI (http://www.sei.ba.gov.br)

This visual model does not constitute a computational representation capable of producing the expected results. Therefore, using the concepts presented by Cormen et al. (2009) when defining the adjacency matrix as one of the most common computational representations in graphs, it is possible to establish a matrix presentation for the distances existing on the edges presented in the network, Figure 3, acting on the existing graphical representation of the Identity Territories network of the State of Bahia.

Figure 3 - Matrix representation with the distances (km) over the network of Territories of the State ofBahia

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	0	335	125	0	0	0	0	0	0	254	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	335	0	201	0	0	0	0	0	0	528	288	83	217	0	0	0	0	0	0	0	0	0	132	0	0	0	0
3	125	201	0	0	0	0	0	0	184	358	0	121	200	160	0	195	0	0	0	0	0	243	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	298	0	0	0	0	97	0	105	83	66	0	0	0	0	0	193	0	0
5	0	0	0	0	0	159	0	141	0	0	0	0	0	0	0	0	0	0	0	0	0	154	0	0	0	0	183
6	0	0	0	0	159	0	0	0	148	0	0	0	0	0	0	0	0	0	0	0	49	123	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	142
8	0	0	0	0	141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	0	156	0	0	0	0	183
9	0	0	184	0	0	148	0	0	0	0	0	0	0	101	0	0	0	0	0	0	137	60	0	0	0	0	0
10	254	528	358	298	0	0	0	0	0	0	648	0	0	0	0	195	266	0	0	0	0	0	0	252	122	0	0
11	0	288	0	0	0	0	0	0	0	648	0	0	0	0	0	0	0	0	0	0	0	0	188	0	0	0	0
12	0	83	121	0	0	0	0	0	0	0	0	0	173	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	217	200	0	0	0	0	0	0	0	0	173	0	0	0	0	0	0	0	115	0	175	0	0	0	0	0
14	0	0	160	0	0	0	0	0	101	0	0	0	0	0	74	152	0	0	149	0	124	0	0	0	0	0	0
15	0	0	0	97	0	0	0	0	0	0	0	0	0	74	0	85	0	0	194	0	0	0	0	0	78	0	0
16	0	0	195	0	0	0	0	0	0	195	0	0	0	152	85	0	0	0	0	0	0	0	0	0	144	0	0
17	0	0	0	105	0	0	0	0	0	266	0	0	0	0	0	0	0	164	0	0	0	0	0	60	0	0	0
18	0	0	0	83	0	0	0	0	0	0	0	0	0	0	0	0	164	0	94	0	0	0	0	0	0	86	0
19	0	0	0	66	0	0	0	0	0	0	0	0	0	149	194	0	0	94	0	0	94	0	0	0	0	138	0
20	0	0	0	0	0	0	0	77	0	0	0	0	115	0	0	0	0	0	0	0	0	82	0	0	0	0	0
21	0	0	0	0	0	49	0	0	137	0	0	0	0	124	0	0	0	0	94	0	0	0	0	0	0	193	0
22	0	0	243	0	154	123	0	156	60	0	0	0	175	0	0	0	0	0	0	82	0	0	0	0	0	0	0
23	0	132	0	0	0	0	0	0	0	0	188	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	252	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0
25	0	0	0	193	0	0	0	0	0	122	0	0	0	0	78	144	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86	138	0	193	0	0	0	0	0	0
27	0	0	0	0	183	0	142	183	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Authors

Considering the value 0 (zero) as the inexistence of a neighborhood, from the data presented, when applying Kruskal's algorithm, a backbone is obtained, Figure 4, considering the smallest distances between network neighbors at a cost of 2,709 km from a total of 10,324 km, thus establishing the shortest path and contemplating all network nodes, configuring a transmission backbone with a reduction of approximately 73.76% in relation to the total.

Figure 4: Graphical representation of the backbone generated by the Kruskal algorithm

T1	T2	Distance
6	21	49
9	22	60
17	24	60
4	19	66
14	15	74
8	20	77
15	25	78
20	22	82
2	12	83
4	18	83
15	16	85
18	26	86
19	21	94
4	15	97
9	14	101
4	17	105
13	20	115
3	12	121
10	25	122
1	3	125
2	23	132
5	8	141
7	27	142
3	14	160
5	27	183
11	23	188

Source: Adapted from SEI (http://www.sei.ba.gov.br)

4.1.2 Comparison between the Kruskal and Prim algorithms

Although the proposed model does not explore time complexity over algorithms, as mentioned above, especially when working in a matrix scenario with the dimensions presented, it is possible, for scenarios that present themselves with a very large volume of nodes and edges, to use techniques that consider this relevant characteristic.

Thinking about this situation, it is possible to make use of the Prim algorithm, which despite applying the same technique of greedy algorithms, which according to Cormen (2011, p.347) is "always makes the choice that seems to be the best at the moment in question. That is, it makes a locally optimal choice in the hope that this choice will lead to a globally optimal solution.", represents an alternative for obtaining the backbone.

The algorithms, Kruskal, Figure 5, and Prim, Figure 6, establish, respectively, a search considering all edges of the graph and a search considering all edges connected to the set defined by the discovery, until, in both cases, the minimum tree represented by the network can be generated.

Figure 5: Kruskal algorithm.

```
MST-KRUSKAL(G, w)
A = ∅
for each vertex v ∈ G.V
    MAKE-SET(v)
sort the edges of G.E into nondecreasing order by weight w
for each edge (u, v) ∈ G.E, taken in nondecreasing order by weight
    if FIND-SET(u) ≠ FIND-SET(v)
        A = A ∪ {(u, v)}
        UNION(u, v)
return A
```

Source: Cormen (2009, p.631)

Figure 6. Prim Algorithm.

```
MST-PRIM(G, w, r)
for each u ∈ G.V
    u.key = ∞
    u.π = NIL
r.key = 0
Q = G.V
while Q ≠ ∅
    u = EXTRACT-MIN(Q)
    for each v ∈ G.Adj[u]
        if v ∈ Q and w(u, v) < v.key
            v.π = u
            v.key = w(u, v)
```

Source: Cormen (2009, p.634)

4.2 A Modeling from the Network Nodes

The modeling through *vertex cover*, different from *Kruskal* and *Prim* that acts on the edges of the network, aims to identify what is the minimum subset of nodes connected on all edges of the network, making it possible to establish a collaborative relationship between neighbors with the goal, within the scope of the research, of identifying which territories could act as a minimum set of energy production *hubs* within the state of Bahia.

According to Dharwadker (2006), in his publication *The Vertex Cover Algorithm*[5], the algorithm for the *vertex cover* is presented in C++ programming language with all the implementation details, therefore, the same algorithm was adopted for the identification for this solution, considering that the objective is not to present a new solution to the vertex cover problem and not an alternative to its complexity, bus as mentioned before, it is only to find the minimum coverage of vertices in the network.

From the execution of the *vertex cover* algorithm, two solutions were found for a minimum set of 16 (sixteen) nodes in the network, they are:

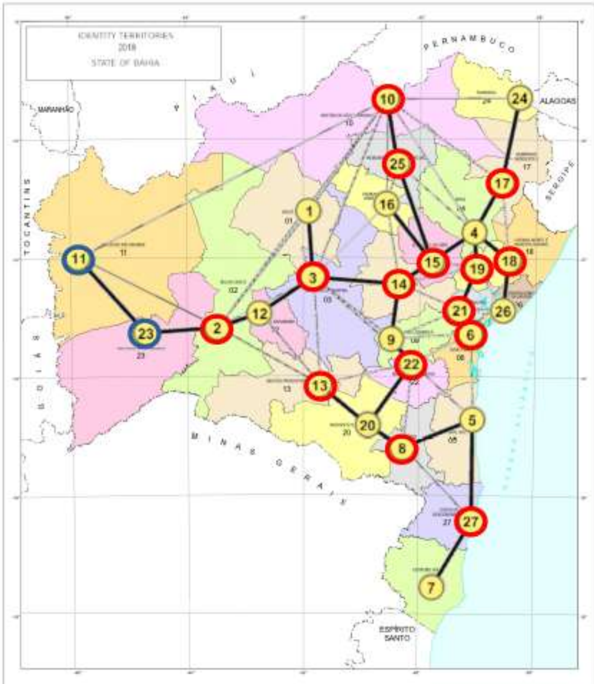
[5] https://www.dharwadker.org/vertex_cover/vertex_cover.pdf

(a) Solution 1: (S_1) = { 2, 3, 6, 8, 10, 11, 13, 14, 15, 17, 18, 19, 21, 22, 25, 27 }

(b) Solution 2: (S_2) = { 2, 3, 6, 8, 10, 13, 14, 15, 17, 18, 19, 21, 22, 23, 25, 27 }

Within the scenario presented, it is possible to realize that the difference between the subsets S_1 and S_2 obtained, corresponds to the territories 11 (eleven) and 23 (twenty-three), Figure 7, identified by the blue color in the node, but that does not present a relevant change in the topological structure, since, in both cases, all territories are contemplated in a neighborhood relationship, even if considered the possibility of a redundancy or cliques, defined by Lintzmayer and Mota (2021, p. 285) as "Let G be a graph and $S \subseteq V(G)$ be any set of vertices. We say that S is a clique if all pairs of vertices in S are adjacent," over the network *backbone* in a future work.

Figure 7: Graphic representation of the network generated by the Vertex Cover algorithm



Source: Adapted from SEI (http://www.sei.ba.gov.br)

From the data presented, by applying the *vertex cover* algorithm, a subset is obtained with the smallest possible number of nodes in the network, with at least one edge incident on it, so that, regardless of the application of redundancy on the defined network, the possibility of obtaining production *hubs* acting on all the neighborhood relationships between the territories of the state of Bahia, produces a reduction of approximately 40.7% in relation to the total number of territories.

4. *3 A Modeling from the Current Scenario*

The current model, for the clipping performed on the research locus, comprises a total of 57 substations (SE), catalogued as of the Transmission Map of the Electric Sector[6] of the National Electric Energy Agency (ANEEL). This set, represented by the physical location of each substation catalogued, constitutes only over a total of 17 Identity Territories, Figure 8.

[6] https://sigel.aneel.gov.br/portal/home/webmap/viewer.html?webmap=3ee2fe1d374a40b483440104857df021

Figure 8: Map of Electricity Sector Transmission by Territory (Bahia)

Source: Adapted from ANEEL (https://sigel.aneel.gov.br)

This construction, adopting the same mapping criteria of the proposed model, was carried out considering only the Transmission Lines (LT) connecting the Identity Territories, Table 2, generating a distance over these relations, of 3,672.67 Km over the mapped network.

Table 2: List of the LT's that connect Identity Territories

SE1 (T)	SE2(T)	LT Name	Voltage(Kv)	Extension (Km)
23	11	Line LT 500 kV BARREIRAS II /RIO DAS EGUAS CN2 BA	500	239,27
23	2	Line LT 500 kV RIO DAS EGUAS / BOM.JES.LAPA IIC L1 BA	500	322
11	2	Line LT 230 kV B.JESUS LAPA / BARREIRAS C L1BA	230	233,5
2	13	Line LT 230 kV BOM.JES.LAPA II / IGAPORA II C F6BA	230	115
13	3	Line LT 500 kV IBICOARA / IGAPORA III C L4 BA	500	174,2
2	3	Line LT 500 kV BOM.JES.LAPA II / IBICOARA C L4BA	500	232
13	20	Line LT 230 kV IGAPORA III / PINDAI II C N1 BA	230	49,6
3	20	Line LT 230 kV BRUMADO II / IBICOARA C F5 BA	230	105
20	22	Line LT 230 kV ITAGIBA / BRUMADO II C Z1 BA	230	234
22	5	Line LT 230 kV FUNIL / ITAGIBA C F4 BA	230	29
5	27	Line LT 230 kV FUNIL / ITAPEBI SE C F7 BA	230	200

3	21	Line LT 500 kV IBICOARA / SAPEACU C L3 BA	500	257
21	26	Line LT 230 kV CAMACARI II / G.MANGABEIRA CC7 BA	230	83,7
21	19	Line LT 230 kV TOMBA / G.MANGABEIRA C S2 BA	230	37,5
19	26	Line LT 230 kV CAMACARI II / TOMBA C S1 BA	230	121,2
21	5	Line LT 230 kV STO.A.JESUS / FUNIL C F2 BA	230	161,9
1	21	Line LT 500 kV MORRO CHAPEU2 / SAPEACU C N3BA	500	300
2	1	Line LT 230 kV BROT.MACAUBAS / IRECE C F2 BA	230	135
1	25	Line LT 230 kV SR.BONFIM II / IRECE C F1 BA	230	214,5
25	10	Line LT 230 kV JAGUARARI-SE / JUAZEIRO II C N1BA	230	80,4
26	18	Line LT 500 kV OLINDINA / CAMACARI II C L4 BA	500	147,2
17	26	Line LT 230 kV CIC. DANTAS / CATU C L2 BA	230	200,7

(T) Identity Territory Code

This network identified over the Identity Territories, Figure 9, despite not presenting itself as a *backbone* due to the existing cliques with some LT's, represents a model where the communication process about theenergy flow can be done from any territory to any territory in the network, thus characterizing a connected graph.

Figure 9: Representation of the LT's that connect Identity Territories

Source: Adapted from ANEEL (https://sigel.aneel.gov.br)

Still on the identified network, it is possible to establish an expansion process over the presented cutout,due to the existing flows in the SE that connect with SEs outside the contour delimited by the scope of the research, present in the Identity Territories 23, 10, 26, 17 and 18.

5. Conclusion

The techniques of computational modeling supported by concepts that are linked to the Graph Theory has proven to be a strong ally to obtain optimal results in solving various problems in various areas of knowledge, in this sense, approaching themes that converge to the sustainability of renewable energy resources in Brazil, linking to this process, as a consequence of this production model, not only an improvement in the quality of life of a large part of the population that is invisible to this resource, but also the balance of the production capacity of the existing natural resources, impacting on the financial costs that the current model imposes on us, as well as the contributions on the existing impacts on climate change, constitute an important object of study.

In this sense, based on the data presented in the article, it was possible to present an implementation model supported by the existing concepts in Graph Theory, but this close relationship demands, considering the various existing complexities that impact within the implementation of an energy production matrix, not only technical issues, but a whole environmental and legal support that involves a production of this magnitude.

Thus, although the focus of this work does not contemplate this theme, it is possible to define criteria for the computational modeling approached with the objective of bringing the proposed model closer to a local reality, considering all the elements that dialogue with the expansion of the energy matrix in Brazil, especially in Bahia, as a way to improve the proposed model to a scenario closer to the local reality.

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