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An Assessment of Accessibility from a Socially Sustainable Urban Mobility Approach in Mass Transit Projects: Contributions from the Northern Central American Triangle

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Abstract: This article aims to address the lack of research on the social dimension of sustainability, also known as social sustainability, in urban mobility projects, primarily in cities of the Global South. It proposes a strategy to partially assess social sustainability, focusing on accessibility, which is one of the key dimensions for conducting such an evaluation. To this end, a comparative analysis of three study cases is conducted in the capital cities of the Northern Central American Triangle (NCAT) before and after the construction of bus rapid transit (BRT) projects between 2000 and 2020. Accessibility is evaluated through equity and spatial efficiency indicators obtained through geographical information system (GIS) modeling, including layers representing transportation networks, populated areas, and locations of basic urban facilities. The result is an unprecedented assessment of accessibility in the NCAT capitals, which shows how the Guatemala City BRT project has improved the city's social sustainability by reducing access times to basic urban facilities, mainly public health clinics and educational facilities, and narrowing the inequality gap as compared to projects in San Salvador and Tegucigalpa, the other capital cities in the NCAT. Additionally, it is emphasized that this methodology can be replicated in the Global South while considering the scarcity of information and the use of open-source software in the process.

Keywords: urban planning; accessibility; BRT; equity; global south

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1. Introduction

Divergent assessments of sustainable development have been noted by scholars [1–4]. Dimitriou [5] emphasizes that sustainability in the field of transport can be perceived as a neo-imperialist notion that neglects local values. Urban mobility schemes in the Global South often overlook the social component of sustainability, implicitly assuming accessibility, inclusion, and equity in all transport services. To address this issue, Dimitriou suggests incorporating context-sensitive sustainable transport strategies.

The ideas about sustainable development that guide urban mobility projects and policies often end up excluding vulnerable social groups, leading to enormous expenses on projects that do not function properly and leaving a gap in efforts to improve the quality of life in more sustainable cities. On this matter, Dimitriou suggests incorporating sustainable transport strategies that are more sensitive to the specific context of each location.

This article proposes the Socially Sustainable Urban Mobility (SSUM) approach as an alternative to make sustainability context-sensitive, specifically in the Global South. The article analyzes three urban mobility modernization projects in the Northern Central American Triangle (NCAT) that were developed in the early 2000s and based on bus rapid transit (BRT) systems.

Although studies had been performed in the three countries of Guatemala, Honduras, and El Salvador pointing out the need to transform their mass transportation systems [6–8], the three initiatives gained momentum after being electoral promises made by mayoral candidates in the cases of Guatemala City and Tegucigalpa and by the central government in the case of San Salvador. This is not uncommon in the realm of transportation projects, as there is evidence that transportation initiatives can be influenced by partisan political considerations, an aspect that Flyvbjerg [9] defines as one of the four "sublimes" that together explain the magnitude of and increase in these projects.

Latin America has the highest number of BRT users worldwide, accounting for 59.5% [10]. However, the increase in private vehicles shown in Figure 1 highlights the unsustainability of urban mobility in the NCAT, which poses significant challenges. It is worth noting that the marked increase in motorbike use is contributing to a 44% rise in road crash fatality rates in low- and middle-income countries, as reported by Neki et al. [11]).

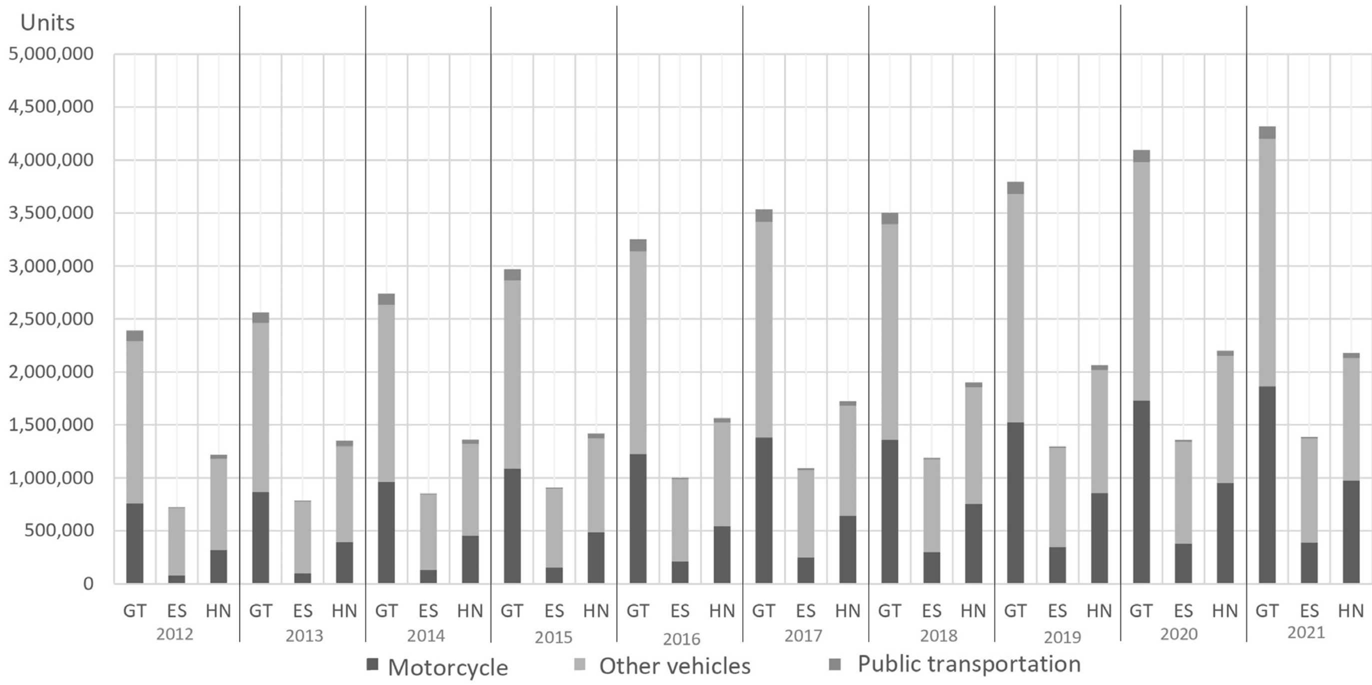

Figure 1. A decade of evolution in transportation modes in the NCAT. Source: Own elaboration based on [12–14]. Note: GT = Guatemala; ES = El Salvador; HN = Honduras.

However, public transportation persists as the primary mode of mobility in the three countries of the NCAT, with the utilization rates reaching 70% in San Salvador and Guatemala and approximately 60% in Honduras [8,15,16]. It is imperative to emphasize, nonetheless, that during the data collection for this research, a notable deficiency in measuring non-motorized travel and its proportion in daily journeys was evident. This lack of information highlights a substantial obstacle for conducting a meticulous assessment of the contribution of non-motorized travel to the public transportation system.

Therefore, this article contributes to the academic discourse in two ways. Firstly, it presents evidence on the social dimension of sustainability by assessing accessibility in an understudied region and in a widely used mode of transport. Additionally, it provides a methodological approach to assessing SSUM in urban mobility projects in urban areas of the Global South, using the NCAT countries as a case study. This article, which focuses on accessibility, is part of a broader research project examining SSUM in three critical categories, namely accessibility, community sustainability, and institutionality as shown in Figure 2.

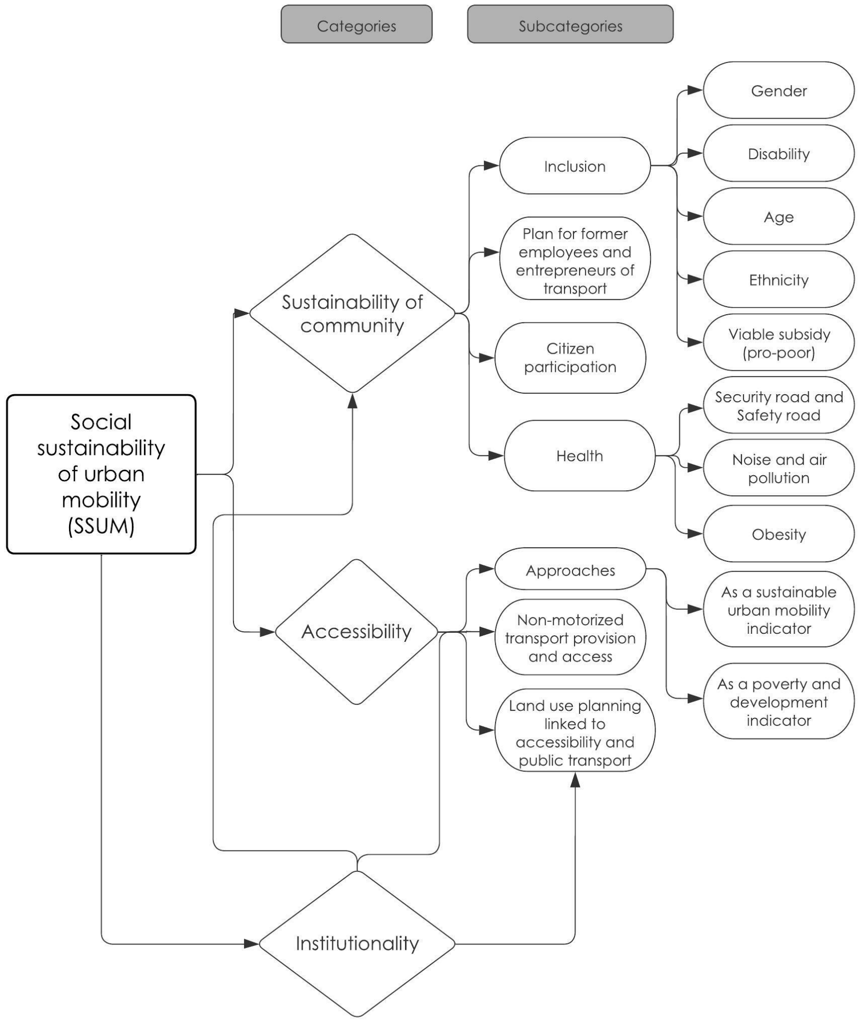

Figure 2. Synthesis of the conceptual framework for social sustainability in urban mobility. Source: Own elaboration based on [17].

Socially Sustainable Urban Mobility as an Analytical Focus in the NCAT

In relation to the SSUM approach in the NCAT, the contributions of Shirazi [3] are relevant when warning of the lack of academic attention to the social dimension of sustainable development theorization, evidencing its ambiguity, limited focus on developed countries, and predominant use in public policymaking. On this issue, Lineburg [17] demonstrates that the academic discourse on sustainability and transport tends to prioritize economic and environmental aspects, often relegating social considerations.

Despite these assertions, Vallance et al. [18] argue that there is a multiplicity of perspectives and contributions that help to define social sustainability, highlighting the urban planning approach [19], which suggests that to promote the social dimension of sustainable development it is essential to ensure equity and inclusion in urban transformation projects.

These principles on social sustainability in urban mobility research are recurrent and fundamental to understanding how transport projects can affect the social dimension of sustainable development. This article proposes four relevant conceptualizations of social sustainability to enrich the urban planning theory from the perspective of urban mobility systems and to provide continuity to the scholarly discussion on the importance of the aforementioned principles of equity and inclusion in social sustainability assessments. Lineburg [17] provides the structure shown in Figure 2, based on the concepts of community sustainability and accessibility, which have also been identified by other authors [20] as indicators for equity and inclusion assessment. Flora [21] and Cervero [22] provide useful resources for a thorough understanding of the implications of equity (horizontal and vertical [23]) and inclusion in transport, which can help in understanding the social dimension from the perspective of the Global South, as well as the research by Pitarch-Garrido [24], which is methodologically relevant to this article.

Furthermore, Flora and Cervero [21,22] emphasize the importance of accessibility as an evaluation category in the SSUM, highlighting it as an indicator that helps to meet the requirement of measuring equitable access to urban amenities and employment, mainly through non-motorized mobility modes and land use planning in conjunction with public transport.

Additionally, this article supports the ideas of several authors [25–28], who argue that in the context of Global South countries, it is essential to incorporate a third category in the SSUM related to the inclusion of the political and institutional dimensions in order to achieve equitable mobility and build sustainable communities.

With these elements described in Figure 2 and mentioned above, it is possible to state that urban mobility will be socially sustainable when the benefits it generates in the city, namely the improvements in accessibility and community sustainability, are equitably and impartially distributed among the population, due to the participatory management of the leading institutions of the sociotechnical system of urban mobility, composed of transportation, land use and stakeholders.

However, this article focuses exclusively on an accessibility assessment as a category of SSUM and poses a specific research question: "From a SSUM approach, how can the assessment of accessibility be employed to measure progress in the social dimension of sustainable development in urban mobility projects in the capitals of the NCAT?"

This reasoning led to the formulation of the hypothesis, which suggests that in the Northern Central American Triangle, urban mobility interventions that incorporate aspects of social sustainability as a structuring focus contribute more significantly to the transformation of a city's exclusionary social structures than those that do not consider these aspects.

The next section justifies the selection of study cases, outlines the characteristics of the BRT projects and cities studied, details data management and quality processes, explains the research techniques and indicator selection, and discusses the impacts of these elements on the obtained results.

2. Materials and Methods

The research methodology aligns with the research question by selecting accessibility indicators linked to social sustainability. In line with Pitarch-Garrido's proposal [24], this study employed the concept of spatial equity to examine how the allocation of economic resources for a mass transit project has altered the population's access to educational, healthcare, recreational, and essential supplies located in urban facilities.

Spatial equity is a key indicator in assessing accessibility from the perspective of SSUM and can be defined as the ability to "meet local needs through efficient resource allocation to promote positive effects in space and overcome challenges related to the physical and social environment" [29]. It is important to note that the analysis of accessibility to urban services should also consider the levels of service provided and satisfaction, with an emphasis on sectors of the population that do not benefit from urban mobility. This article addresses this issue further in the discussion section.

From the vantage point of urban planning, this paper introduces an alternative methodology grounded in the use of open-access tools. It provides a comparative analysis of three BRT projects, evaluating their impacts on the overall quality of life. This evaluation integrates statistical and cartographic indicators. Notably, the research accentuates a SSUM approach, encompassing considerations such as the role of accessibility in fostering sustainable communities and its interconnectedness with social equity. It is pertinent to acknowledge that due to the scope of this article, the relevance of the institutional domain remains unexplored.

The selection of the study cases involving the three capital cities from the Northern Central American Triangle region was based on the significant number of commonalities between them. These include the implementation of BRT systems for mass transport, their significant urban growth between 1990 and 2014, and the fact that they are conurbations and that have similar percentages of population in relation to the country as a whole (around 30%), among other aspects highlighted by Maria et al. [30], suggesting a certain degree of homogeneity among the selected cities.

However, despite these similarities, it is important to note that the three cities have achieved very different outcomes in their urban mobility projects. These differences present a unique opportunity to conduct comparative case studies and derive relevant interpretations. Moreover, these characteristics add interest to the comparative evaluation of ex ante and ex post BRT projects in NCAT countries and bridge the information gap on accessibility in that region, providing a valuable example of "maximum variation" [31], allowing for the evaluation of urban mobility projects in similar contexts but with different results.

The temporal threshold selected was between 2000 and 2020, during the planning and implementation of BRT projects, focusing solely on the limits of the NCAT capital cities, the border lines of which have been depicted in red in Figure 3.

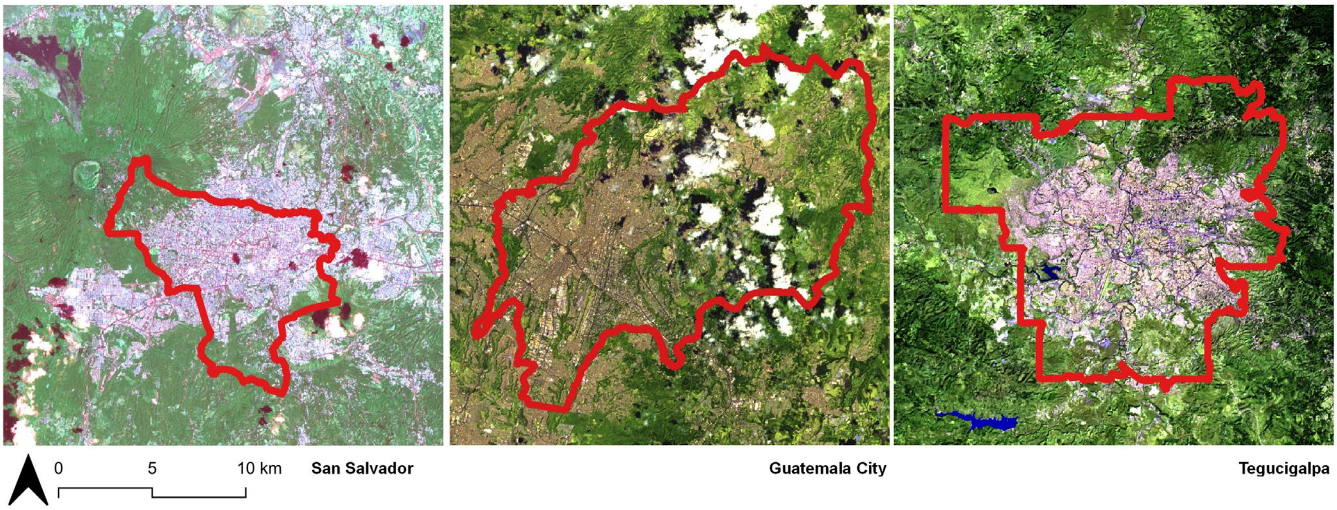

Figure 3. Urban growth of metropolitan areas in the NCAT. Source: Author's elaboration based on Sentinel 2 satellite images.

The description of the metropolitan areas can be brief, as those of the three NCAT capital city's house almost 9.9 million people. However, the capitals alone have a combined population of 2.78 million [32]. The three BRT systems of the NCAT capital cities have had diverse outcomes. Guatemala's TRANSMETRO remains operational, serving 210,000 daily passengers (approximately 17% of their population) across seven lines spanning 60 km. In contrast, San Salvador closed its 6 km BRT system in 2020, which had catered to 27,000 daily passengers (approximately 8% of their population). Although Tegucigalpa constructed a significant portion of infrastructure over a distance of 10 km, the project was never operationalized.

As outlined in the Introduction, accessibility is essential in an analysis of social sustainability. The concepts of accessibility can take various approaches, traditionally linked to disciplines such as urban economics, human geography, and city planning. In the former, as asserted by Goodall [33] and Camagni [34], accessibility is understood as a category that enables decision-making in the selection of business and residential locations to reduce travel costs within the city. Human geography emphasizes the accessibility levels of social groups, their locations, and the different levels of exclusion that are generated or perceived [35].

Methodologically, accessibility is used as an indicator for different purposes in different disciplines. In urban planning, Zegras [4] defines it as a robust indicator of sustainable urban mobility, which depending on the methodology can efficiently integrate the various components that shape its evaluation. The concept of accessibility is defined by Geurs and Van Wee [36] "as the extent to which land use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)". This concept was adopted in this research for its comprehensiveness and the usefulness of its four evaluation perspectives. This study adopted the location-based evaluation perspective, as advocated by Zegras [4], which is capable of delineating spatial groupings in strata and population segments under conditions of exclusion, justifying its selection.

Hansen's [37] potential accessibility approach is widely used in urban planning as a measure of accessibility, as it assesses the inequality of opportunities in a territory due to origin, the locations of available services, distances, and the means of transport to access them. Since its creation, adjustments have been made to refine this measure, although the lack of empirical data on the attractiveness of trips to urban facilities (3590 in Table 1) in the capitals of the NCAT hinders its usefulness.

Given the availability of data, the alternative proposed by Moreno [38], which uses optimal location models (OLMs), has many advantages. OLMs have various applications, including the ability to establish a network of services and facilities and evaluate spatial schemes of current endowments, so our comparative evaluation used this process to focus on accessibility as an indicator of the SSUM.

Our optimal location model (OLM) [38] operationalized a location-based accessibility evaluation, using a 15 min tolerance parameter to identify levels of population exclusion and territorial inequalities before and after BRT projects. This study employed open-source software such as QGIS 3.32.0 and Flowmap 7.4 [39] to ensure process replication in resource-constrained contexts and to meet scientific requirements. QGIS was used to present the results, while Flowmap is used for impedance calculations and accessibility assessments.

The collected data were diverse, as there is no standardized data infrastructure (IDE) in Central America to facilitate the harmonization and exchange of information, similar to the INSPIRE initiative in Europe [40]. The selection process was complex not only due to the variety of information but also because the data originate from different institutions and countries following different standards of capture and indexing. Therefore, the data selection criterion was based on ensuring that the selected layers enabled the construction of a model that allowed a comparison between cities and included aspects such as census tracts, public transportation routes, road infrastructure, and the locations of basic urban amenities. Once the information was identified, the datasets displayed in Table 1 were selected.

The collected data required careful cleaning due to limitations in the bus stop locations and route frequency rates, resulting in a loss of precision in the network impedance calculation. The diversity of sources demanded meticulous homogenization of the information to generate territorial models (see Figure 4). The capacity of each facility was verified, and the existence of public spaces and public health clinics was validated through municipal portals and health ministries for all countries. Private educational institutions were also included, taking into account the approximately 50% public–private distribution in the three countries [12,41], as well as markets and supply centers.

The territorial models developed for each of the NCAT capital cities included the intermodal road network, which comprises pedestrian, conventional bus, and BRT systems. The road network topology was adjusted, and routes and commercial speeds for conventional buses, BRT, and pedestrians were examined.

The territorial model can be characterized as static in terms of demographics and infrastructure. In this sense, these variables remain constant and provide a snapshot at a specific point in time, offering a basic understanding of the state in which the model was developed in 2021. However, this highlights its ability to describe the impacts of the BRT system on the territory, which is dynamic. This suggests a future line of work focused on exploring and improving the representation of static variables to better approximate the effects of BRT implementation in future iterations of the model.

To calculate distances between transport planning zones (TPZ) and urban facilities, the method of connecting the network between modes through any connection point was established. This tool produces descriptive statistics based on the origin–destination matrix, which is then used to form three groups of results.

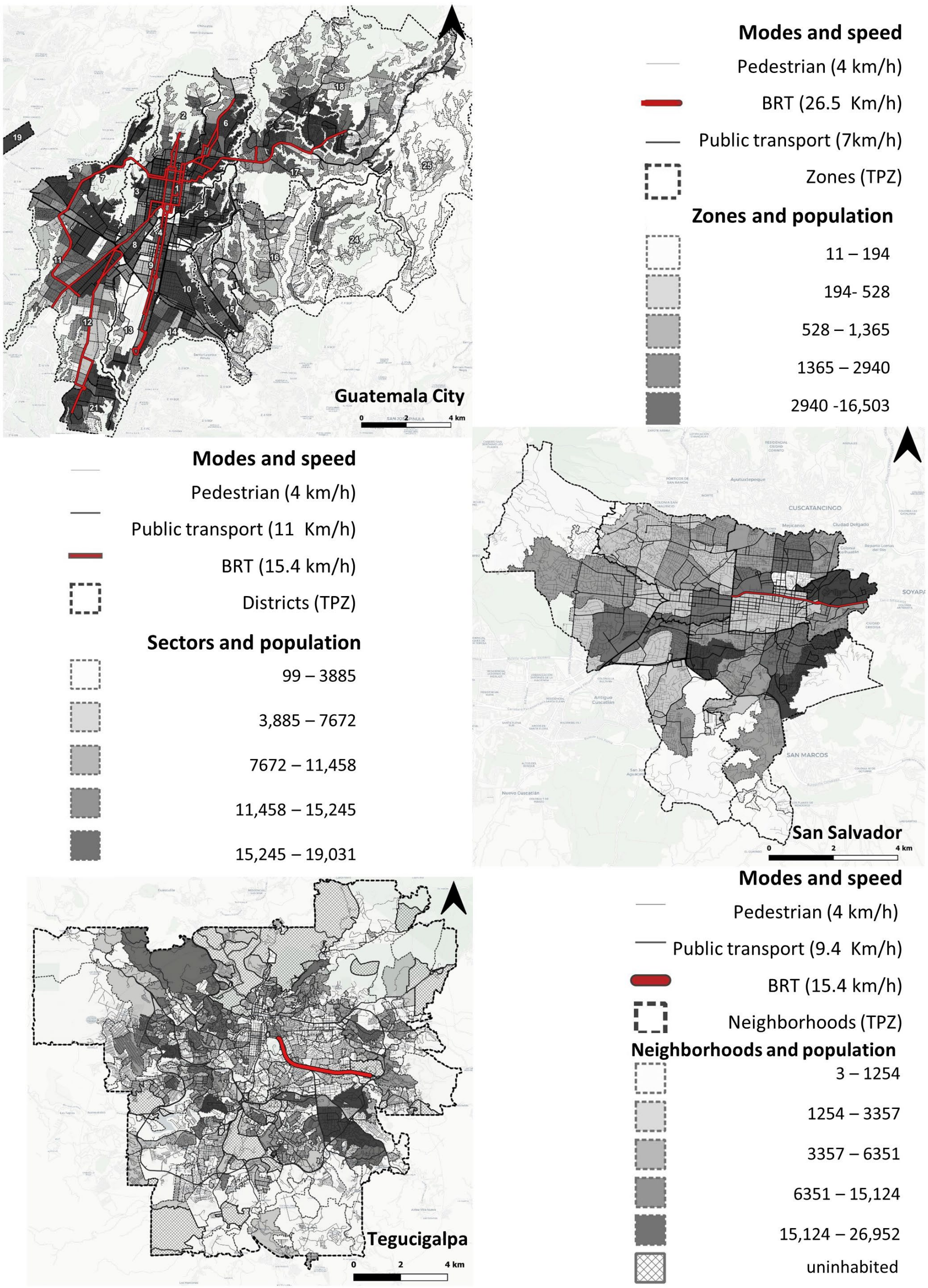

Figure 4. Territorial models of NCAT capital cities. Source: Author's elaboration based on multiple sources described in Table 1.

The first group consists of a series of 15 min area maps that display access times to urban facilities before and after BRT projects. These maps quantify the population that is excluded from access to urban facilities. The second group presents spatial efficiency indicators, which describe the population using descriptive statistics over time ranges and evaluate the data dispersion across these ranges through variance. This allows for an analysis of territorial inequalities before and after the BRT project, highlighting differences and territorial exclusions.

Finally, the third set of indicators includes the Gini Index, which as indicated by Van Wee and Mouter [42] is widely used to provide data on equity conditions regarding territorial accessibility. In summary, this indicator contributed to the analysis with an exploratory approach to the accessibility condition towards urban facilities in each capital city of the NCAT, thereby marking the beginning of an incipient analysis in terms of equity.

Table 1. Main types of information, characteristics, and data sources.

Type of Information	TRANSMETRO (Guatemala City)	SITRAMSS (San Salvador)	TRANS-450 (Tegucigalpa)
Pedestrian road network—public transportation routes.	[43]	[44] **	[8] and Open Street Map [45] ***
Municipal territory (Ha)	22,852.90 [46] *	7130.20 **	20,406.50 [47]
Speeds	Pedestrian: 4 km; public transportation: 7 km/h [48]; BRT: 26.5 km/h [10]	Pedestrian: 4 km; public transportation: 11 km/h [6]; BRT: 15.4 km/h [10]	Pedestrian: 4 km; public transportation: 9.4 km/h [8]; BRT: 0
Transportation planning zones (TPZs)	670 census tracts, $\bar{x}$ = 17.95 Ha, σ = 11.38 ha, min. = 2.01 Ha max. = 117.89 Ha *	43 sec tors, $\bar{x}$ = 166 Ha, σ = 175 ha min = 19 Ha max. = 980 Ha **	675 neighborhoods, $\bar{x}$ = 24.85 Ha, σ = 70.07 ha, min = 0.23 Ha, max. = 1050 Ha [47]
Number of schools	1331 *	335 **	529 ***
Amount of public space	444 *	280 **	306 ***
Number of grocery stores/markets	136 *	60 **	85 ***
Number of public health clinics	38 *	14 **	32 ***
General population TPZ, % men–women at the municipal level	Census subsegments [43,46]	Municipal sectors [44]	Colonies or residential neighborhoods [47]
Population	1,204,964 [43]	351,130 **	1,230,850
Urban population in metropolitan area	5.1 million	1.8 million	2.9 million
Gross density (Hab/Ha)	54.35	49.24	60.32

Source: Own elaboration based on multiple sources. Note: The symbols *, **, *** refer to the citation in which they first appear.

In summary, the evaluation process for the accessibility to basic urban amenities utilized the methodology of optimal location models through open-source software. This approach enabled the generation of metrics associating accessibility with indicators such as spatial equity, spatial efficiency, and the Gini Index. This process was conducted for each capital city in the Northern Central American Triangle both before and after the implementation of BRT projects. The aim was to compare the results and deduce the impacts of these projects on improving social sustainability.

Two methodological considerations stand out in conclusion. Firstly, while 15 min maps can be helpful, according to Bertaud [49], they do not fully address the complexities of accessibility, as they do not consider the influence of consumer and labor markets on land use. This information is important for effective communication with decision-makers. Secondly, although the methodology identifies areas of low accessibility and affected populations, it does not identify the situations of vulnerable groups due to limitations in the initial data. However, despite these limitations, the initial identification process enables prioritization of interventions to enhance quality of life, aligning with SSUM by emphasizing population accessibility as a measure of efficiency in urban mobility.

3. Results

Figures 5–7 present a visual summary of the results obtained from the accessibility evaluation. Each map displays the locations of urban facilities, using black dots as symbols. The figures demonstrate the evaluations conducted before and after the implementation of the BRT project, except for Tegucigalpa. Despite the construction of a significant part of the infrastructure, the BRT system never operated in Tegucigalpa.

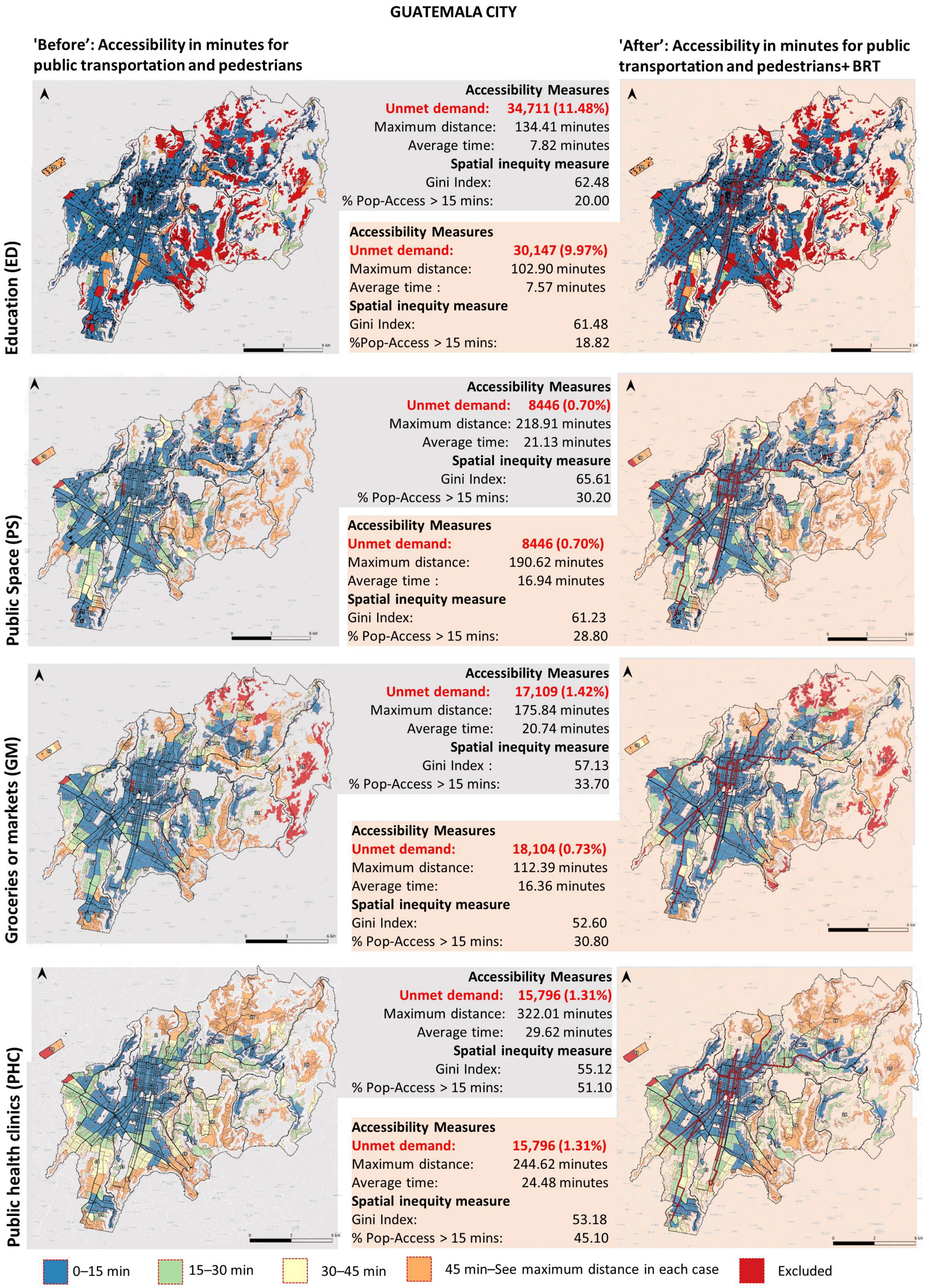

Figure 5. Synthesis of accessibility assessments in Guatemala City.

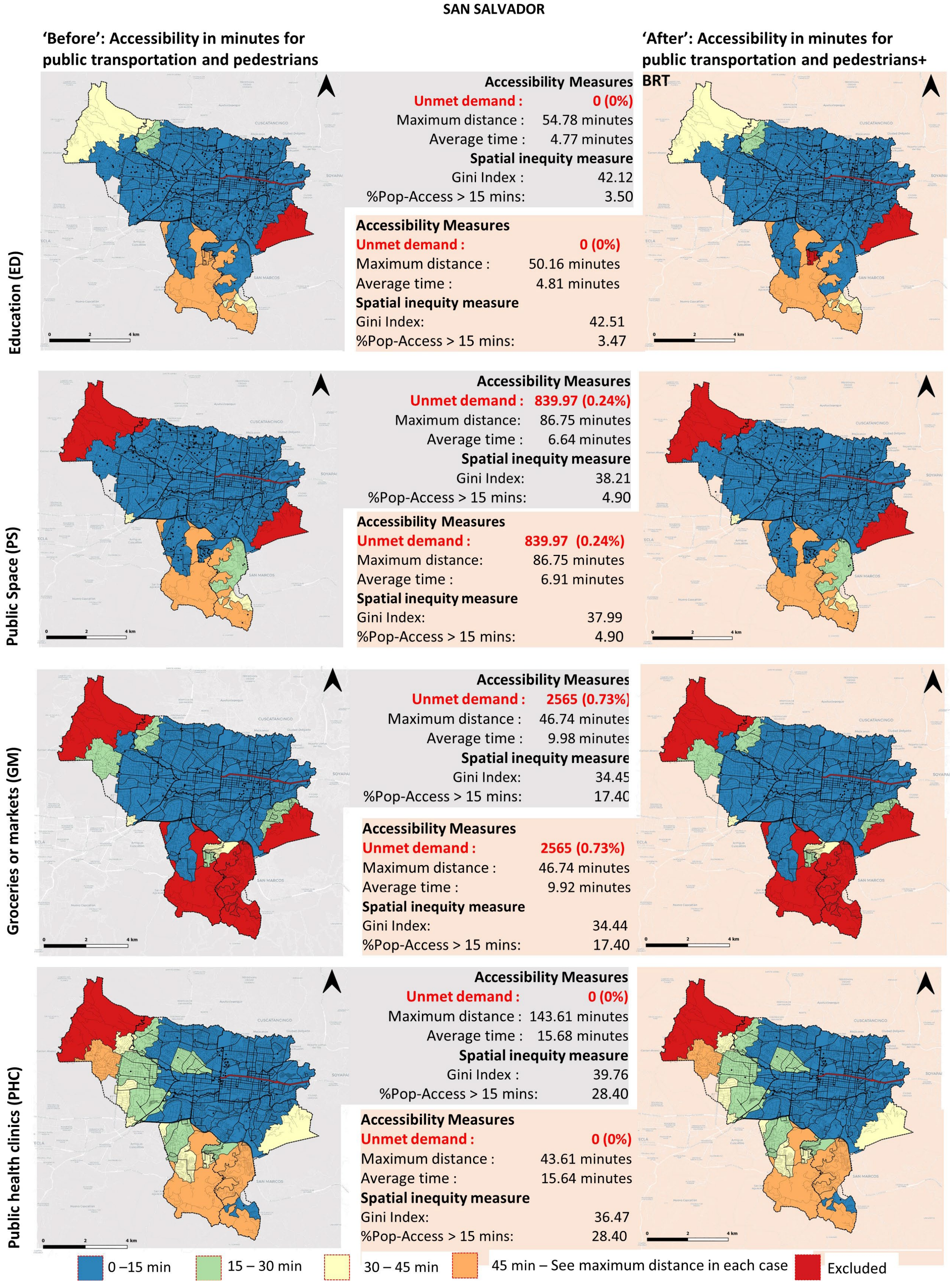

Figure 6. Synthesis of accessibility assessments in San Salvador.

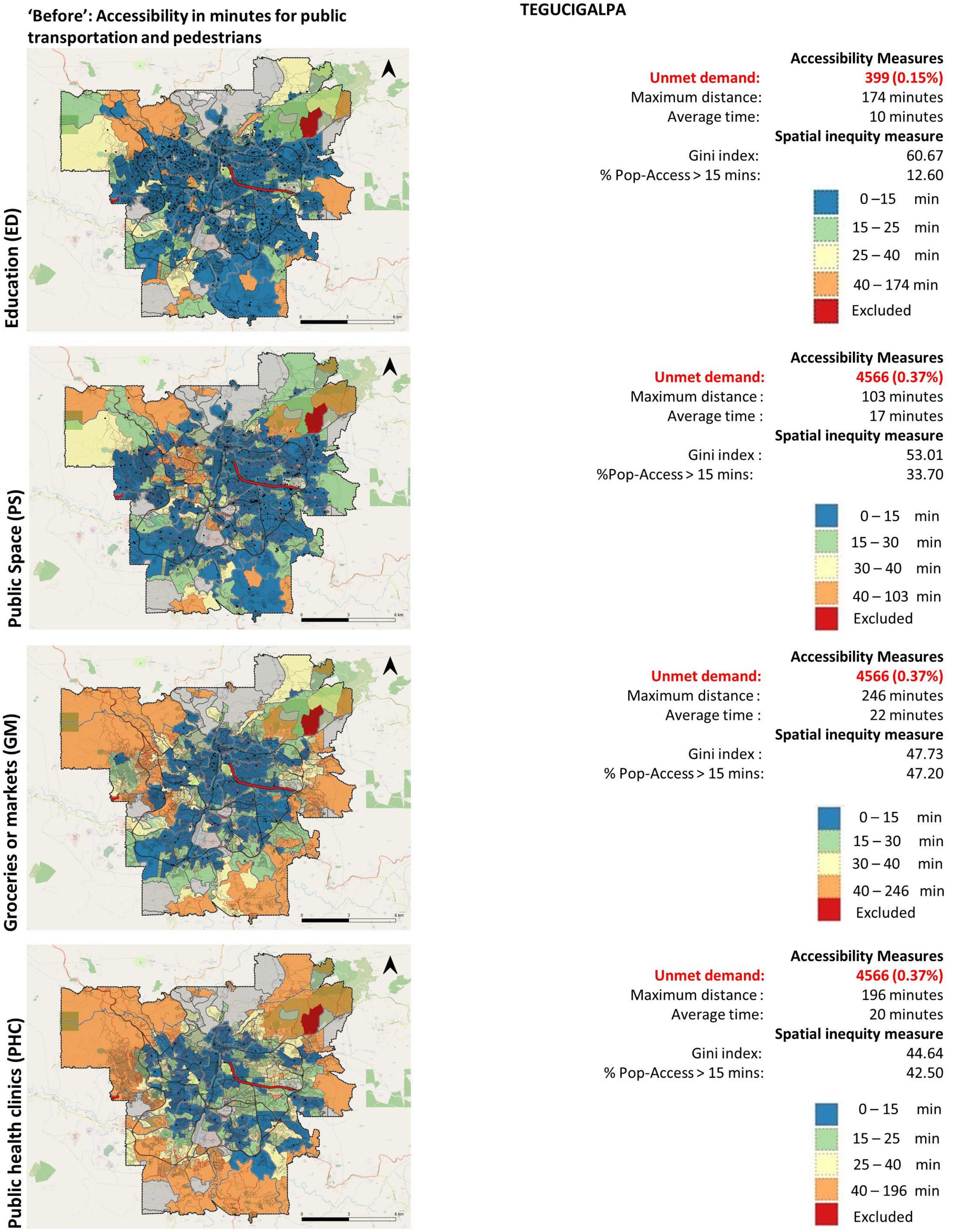

Figure 7. Synthesis of accessibility assessments in Tegucigalpa. Note: Red line in figure depicts BRT projected line.

Table 2 presents the results of the accessibility measurements, using the designations B for 'before', A for 'after', and Δ for the difference between before and after. The values in the Δ field are highlighted in red to indicate increases, while green tones indicate reductions in travel time to urban facilities after the implementation of the BRT project. The urban facilities are labelled with the following nomenclature: education facilities (ED), public spaces (PS), grocery stores or markets (GM), and public health clinics (PHC). The results highlight several aspects.

Table 2. Synthesis of accessibility indicators for the NCAT capital cities.

Indicators/City		**Guatemala City**				**San Salvador**				**Tegucigalpa**			
Population		1,204,964				351,130				1,230,850			
Student population		253,283				105,023				302,325			
Urban facility		ED	PS	GM	PHC	ED	PS	GM	PHC	ED	PS	GM	PHC
Spatial efficiency													
Distance $\bar{x}$ (minutes)	B	7.83	21.12	20.75	29.62	4.77	6.94	9.98	15.68	9.11	16.84	22.1	19.57
	A	7.57	16.94	16.36	24.48	4.81	6.91	9.91	15.64	-	-	-	-
	Δ	0	4	4	5	0	0	0	0	-	-	-	-
Max-Min (minutes)	B	134.4	218.6	175.8	322	54.43	85.6	45.33	140.6	173.5	102.9	245.2	194.5
	A	102.9	190.3	112.4	244.6	49.8	85.6	46.74	140.6	-	-	-	-
	Δ	32	28	63	77	5	0	−1	0	-	-	-	-
σ (minutes)	B	15.6	61.77	32.01	71.43	11.9	15.33	10.58	23.79	17.4	17.67	26.76	28.8
	A	11.33	51.87	27.67	55.66	11.8	15.33	10.58	23.8	-	-	-	-
	Δ	4	10	4	16	0	0	0	0	-	-	-	-
Spatial equity													
Gini Index	B	62.48	65.61	57.13	55.12	42.12	38.21	34.45	39.76	60.67	53.01	47.73	44.64
	A	61.48	61.24	52.6	53.18	42.51	38	34.44	39.93	-	-	-	-
	Δ	1	4	5	2	0	0	0	0	-	-	-	-
Population with accessibility over 15 min	B	50,568	363,706	406,410	616,244	3640	17,258	61,033	99,759	38,197	414,592	581,159	523,079
	A	47,661	346,615	371,399	543,523	3640	17,258	61,033	99,759	-	-	-	-
	Δ	2907	17,091	35,011	72,721	0	0	0	0	-	-	-	-
% of population with >15-min accessibility	B	20.00	30.20	33.70	51.10	3.50	4.90	17.40	28.40	12.60	33.70	47.20	42.50
	A	18.82	28.80	30.80	45.10	3.47	4.90	17.40	28.40	-	-	-	-
	Δ.	1.10	1.40	2.90	6.00	0.00	0.00	0.00	0.00	-	-	-	-

Source: Authors' own elaboration. Note: For the case of the population living near educational facilities, only the population of school age was considered. The equipment columns correspond to educational facilities (ED), public spaces (PS), grocery stores or markets (GM), and public health clinics (PHC). Accessibility measurements: B: "before"; A: "after"; Δ: difference between before and after. Data are highlighted in traffic light code to point out relations among the results. Red tones indicate increases in travel time among the results, yellow tones indicate intermediate increases, while green tones indicate reductions in travel time to urban facilities after the implementation of the BRT project and positive numbers of persons moved to zones with acceptable levels of accessibility.

Firstly, Guatemala City has the highest absolute levels of travel time to urban facilities among the three cities studied. However, the city has also made significant progress in reducing travel times and increasing access to basic urban facilities within a 15 min radius. Approximately 73,000 people now have improved access to health services and around 2900 students (about 1% of the student population) have better access to education facilities within these zones.

Secondly, Table 2 shows that the TRANSMETRO project in Guatemala has significantly reduced the maximum and minimum time intervals for spatial efficiency, particularly in the southwest and northeast regions, as illustrated in Figure 5. The minimum reduction is 28 min for access to public spaces and the maximum reduction is 77 min for access to health facilities. It should be noted that there are also some reductions in daily travel times in San Salvador (around five minutes), although they may be barely noticeable to someone who travels daily.

Figure 8 illustrates the third result for Guatemala and San Salvador regarding the accessibility before (indicated by blue dots) and after (indicated by red dots) the implementation of the BRT projects. The dot size indicates the population, revealing a significant reduction in travel time to public health clinics that serve a large number of people in Guatemala. In contrast, San Salvador shows only slight decreases in access times.

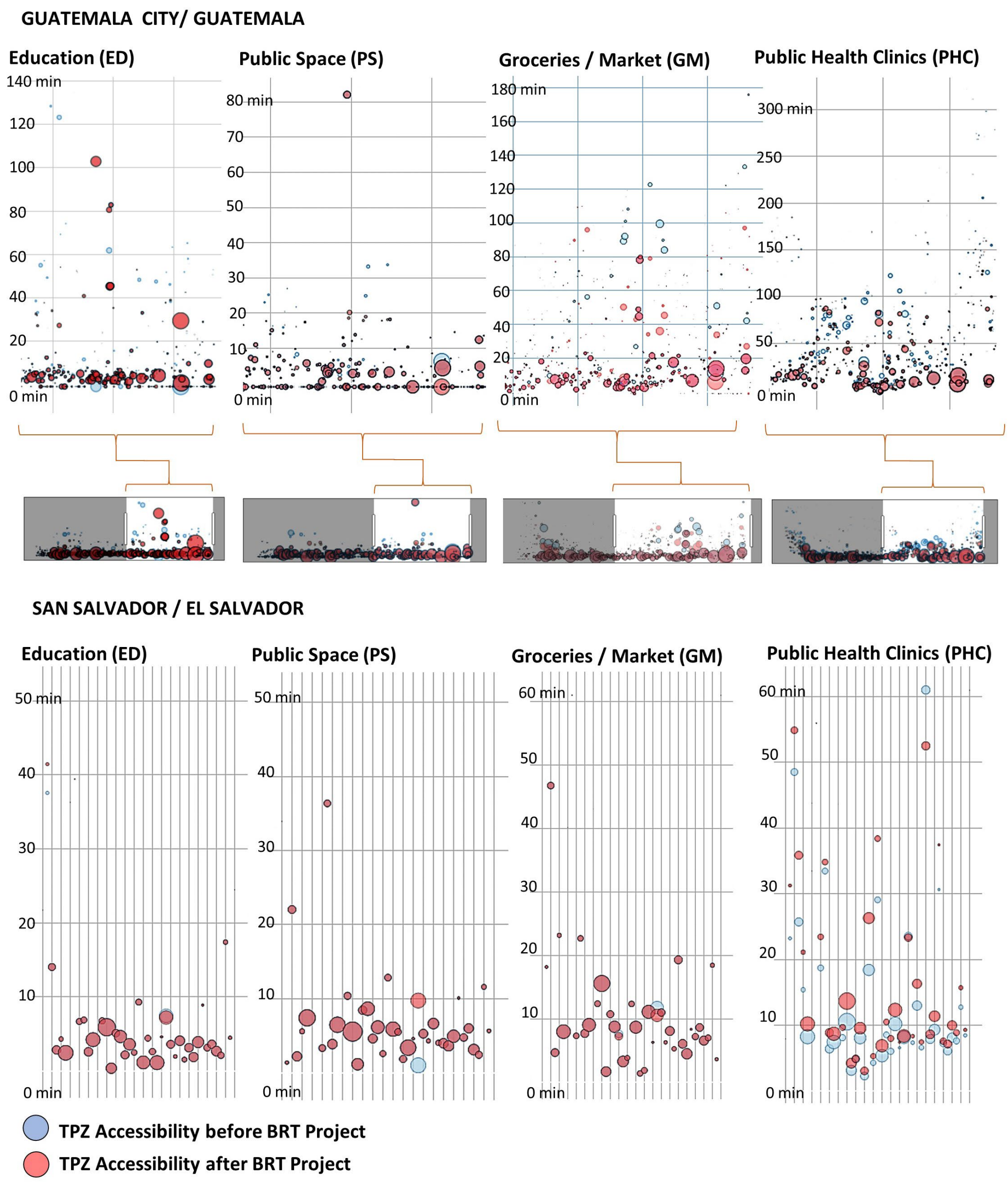

Figure 8. Comparison of TPZ accessibility values in Guatemala and San Salvador before and after BRT projects. Source: From the authors. Note: The sizes of circles representing TPZs are proportional to the population they contain in relation to the total population of the municipality. *Y*-axis shows travel time and *X*-axis is an individual code for each TPZ. For a more detailed view of the graphs in this Figure, you can access the following link: http://bit.ly/3KidLbj (accessed on 1 January 2021).

This evidence highlights the importance of accessibility as a critical measure for evaluating social sustainability. It confirms that the expansion of the TRANSMETRO network has resulted in improved travel times, enabling more people to access essential facilities within a 15 min radius.

The fourth significant finding concerns the SITRAMSS project in San Salvador. Table 2 indicates a minor improvement in travel times, although this is hardly noticeable. As previously mentioned, the impact is mostly negative. This is due to the fact that the constructed section of six kilometers was designed as a 'showcase' area, providing travel benefits for those living outside the municipality but not enhancing the daily life quality of the local residents. In summary, unlike TRANSMETRO, there are limited local benefits to accessing basic urban facilities.

The fifth result shows that the TRANS-450 project in Tegucigalpa has negative values for the 15 min zones, similar to the situation with SITRAMSS. Despite significant investment, TRANS-450 did not improve accessibility as it did not function, indicating a lack of contribution to the social aspect of sustainability.

4. Discussion

The key findings indicate a modest but significant improvement in the municipality of Guatemala in terms of the equity and spatial efficiency of access to basic urban facilities, especially health services and markets, after the BRT project's development (see Table 2). Despite the longer travel times and wider temporal gaps observed in the spatial efficiency indicators (see Max–Min and σ indicators in Table 2), TRANSMETRO, compared to the other two studied countries' systems, is currently the only project that has effectively reduced these gaps in spatial efficiency and equity.

In Guatemala, the population has improved the travel times to all urban facilities, particularly public health clinics. Approximately 6% of the capital's population, around 72,700 people, are estimated to be within a 15 min radius of a public health clinic. It is noteworthy that the Gini Index, as an indicator of equity, shows reductions in the access gaps to all urban facilities, especially market facilities, of up to 5 points. These improvements can be perceived via their respective variations in each TPZ, impacting the overall promotion of social sustainability, facilitating the creation of sustainable communities, and improving quality of life.

Regarding the SITRAMSS project in San Salvador, despite operating for nearly six years, it did not lead to any significant improvement in population access to basic urban facilities, as evidenced by the spatial efficiency and equity indicators. The TRANS-450 (Tegucilapa) project shows absolute accessibility values comparable to those of Guatemala City, although in terms of its progress in reducing the equity gap, it resembles the Salvadoran case. Therefore, it failed to have an impact on the population, even though it received significant infrastructure investments and remained inoperative.

These cases highlight that an investment in public transportation does not always solve the problem of accessibility, particularly when there is not successful integration with the existing urban fabric and infrastructure. The fragmented city has remained but with new challenges to beat due to changes introduced by the new transport infrastructure.

In this regard, the results obtained in Guatemala align with other ex post evaluations of BRT systems [50], suggesting that the successful integration of BRT systems into the existing public transport network and urban environments can achieve positive redistributive effects, especially for lower-income strata of society. TRANSMETRO [16] aimed to achieve this dual integration (existing public transport–urban environment), and these findings are in line with evaluations in the southwest axis [51]. It is, therefore, asserted that TRANSMETRO has contributed significant benefits in regions where middle-income residents tend to use private transport. Based on these results and those shown in Table 2 and Figure 5, indicating greater accessibility in the TPZs and the expansion of TRANSMETRO, the municipality of Guatemala is fostering equity by quickly connecting urban facilities to the entire population.

This assertion could be interpreted as a utilitarian approach to improving accessibility based on one of the theories provided by Pereira et al. [52], i.e., that access is improved without prioritization among beneficiary social groups. However, it could also be conjectured that vertical equity is achieved for at least two reasons.

The first reason, depicted in Figures 5–7, is that the TRANSMETRO project covers a broad territorial network, in contrast to the single-line structures of SITRAMSS and TRANS-450. This provides access to areas that previously lacked efficient transport services. The second reason is that while the outskirts of the NCAT capital cities may contain low-density housing developments for middle- to high-income families, it is also common to find lower-income strata on the peripheries. For the time being, this point represents a starting hypothesis for future lines of research that involve identifying the accessibility situations of vulnerable groups in order to confirm that at least low-income residents have benefited.

In terms of a comparative analysis, it was established that the central areas of the NCAT capitals were well-served both before and after BRT projects (see Figures 5–7). However, as we move away from the center, the quality of access to various services deteriorates. This aligns with the findings of Pitarch-Garrido [24] for the city of Valencia, which suggest that accessibility improvements are extended as transport lines create axes of improvement in the areas near the main corridors.

Within the context of the NCAT, a noteworthy finding is the lack of recognition of the importance of non-motorized mobility (NMM) modes when assessing accessibility, implementing mass transport projects, and overseeing them. Although NMMs are frequently used in the NCAT, their implementation is not addressed with the necessary urgency. For example, Guatemala expressed initial interest in the BRT development plan [16] but faced criticism for not prioritizing NMM infrastructure in the execution of TRANSMETRO [53].

This study contributes by integrating NMMs into the evaluation and planning in the territorial model development process. The results from Table 2 are a consequence of the influence of pedestrian modalities on accessibility and their importance in a multimodal journey. However, there is still a need for more in-depth integration of NMMs. Additionally, it can be affirmed that in peripheral regions where BRT corridors fail to improve accessibility, NMMs are a viable alternative to complement journeys. However, achieving this requires coordination with motorized transport systems and the implementation of institutional policies, at least in terms of management, citizen participation, regulations, and infrastructure, as recommended in [54].

Finally, in order to add nuance to this assessment of accessibility in the NCAT, three aspects need to be considered. Firstly, the results may be considered optimistic due to the lack of data to anticipate wait times when changing modes. Nevertheless, it is crucial to consider this initial assessment as a benchmark for accessibility in the NCAT until accessibility indicators can provide enough information for policymakers to recognize the diversity of people's needs and constraints when making their transportation decisions, as confirmed by Pereira et al. [52].

Second, it highlights the inherent challenge of the SSUM assessment process, as databases do not allow for the segregation of vulnerable groups. It is crucial to emphasize the significant hurdle of conducting this type of research in cities of the Global South, which are characterized by limited access to information and a lack of systematized, especially georeferenced data.

Muente-Kunigami [55] argues that the Latin American region can be compared to Africa and Asia in terms of its lowers scores in indicators such as Global Open Data Index, Open Data Inventory, and Open Data Barometer, which assess countries' strategies for implementing open government data.

Thirdly, the degree of accessibility identified for each TPZ and its urban facilities does not allow the identification of zones with vulnerable populations, such as for education. Factors such as quality, age-segmented data, and the required level of equipment are aspects to prioritize for future improvements.

5. Conclusions

In order to respond to the research question and as a generalization, this article presents two non-exclusive alternatives on how accessibility assessments can be used to evaluate progress in the social sustainability of urban mobility, under conditions of low investment in tools and scarce data, which are recurrent in the Global South.

The first alternative involves obtaining indicators of the spatial efficiency of the urban facilities and transport systems through the assessment of accessibility before and after the implementation of urban mobility projects. This assessment method seeks to identify differentials in impedances (e.g., descriptive statistics of time, distance, money) caused to individuals. These differentials, examined in light of a reference threshold (e.g., a fifteen minute city, minimum wage) will represent progress or regression in the distribution of benefits from transportation systems.

The second alternative pertains to the evaluation of spatial equity. As discussed, it is possible to infer certain impacts on the horizontal and vertical equity levels of transport system users from cartographic and statistical indicators. This article proposes the Gini Index as a global indicator and percentages of individuals included in post-implementation tolerance thresholds as comparative indicators; these results may be more useful if they are matched with additional data on population characteristics such as income level, gender, disability, and age.

On the other hand, it is particularly noteworthy for the capital cities of the NCAT that despite the three BRT projects being developed in similar contexts, the outcomes vary significantly. TRANSMETRO has enhanced the accessibility to basic urban facilities, a crucial element of SSUM. However, an improvement in accessibility alone is not sufficient for SSUM; it is imperative that this enhancement exhibits two key characteristics. Firstly, there must be a noticeable improvement in spatial equity, manifested in reductions in time when accessing basic facilities in various areas of the city. Secondly, the inclusion of population sectors previously distant from an evaluation threshold is needed—conditions observed in Guatemala City.

In comparison with SITRAMSS and TRANS-450, the TRANSMETRO project stands out in terms of both its accessibility indicators (efficiency and spatial equity) and morphological characteristics as a wide-reaching network, with acceptable urban integration into the existing public transport network and built environment and efficient management that allowed for rapid expansion.

These characteristics have had far-reaching effects, including a 70% reduction in air pollution in the southwest axis [56], time savings for residents, and economic and social gains through improved access to existing facilities, avoiding the need for new construction projects. In contrast, SITRAMSS and TRANS-450 have not made progress in terms of accessibility indicators and have experienced a slow and concentrated implementation strategy in specific areas of the territory. Overall, these features highlight TRANSMETRO as a desirable and influential project for improving SSUM and implementing a BRT system.

However, to identify key issues for policy-making, it is essential to evaluate the impact of SUMM on the distribution of benefits among the population in the capital cities of the NCAT. This paper proposes a methodology that can be considered a benchmark for assessing accessibility, as it recognizes the availability of data and resources in the NCAT capital cities.

Nevertheless, this evaluation is preliminary, although it is valuable for planners and decision-makers as it identifies the evolution of the benefits resulting from the reduction in barriers to accessing basic urban services generated by BRT projects. Despite the limitations in identifying vulnerable groups and the impacts on commuting due to information constraints, this equity assessment is novel and provides data on the current situation, factors influencing progress, and identified areas that have benefited and those that require more attention.

Regarding the falsifiability of the hypothesis, the initial results and the detailed conclusions of this article describe at least one of the three elements of SSUM in greater detail, specifically addressing how improvements in accessibility impact the construction of a sustainable community. In this context, Guatemala City serves as a clear example, as the changes brought about by the implementation of its BRT system directly influenced situations of inclusion for individuals, particularly among populations previously lacking services. This improvement in access times to basic needs contrasts notably with the other two case studies.

Finally, regarding future research directions related to policy-making and the research presented in this paper, three areas emerge from the perspective of the Global South. The first relates to identifying how these improvements in inclusion and equity conditions impact the fight against poverty, an outstanding goal of sustainable development. As Godard [57] points out, urban mobility policies and projects are an exceptional tool in the fight against poverty, and not using them in this way in Global South urban mobility projects would be a missed opportunity.

The second line of research concerns the interaction between SSUM evaluations and the environmental and economic dimensions of sustainable development. Moreno and Colsa [58] propose indicators that assess carbon emissions generated by travel, while Garretón [59] suggests techniques that prioritize the identification of economically disadvantaged sectors, both stemming from accessibility assessments.

The two lines described above are complementary when diving into more comprehensive evaluations of accessibility, including data for socioeconomic and environmental issues, which this time could not be included due to a scarcity of information.

Finally, a third line of inquiry should seek to refine the territorial model presented in this article with improvements to the database, detailing the calculation of impedances and determining strategies to identify vulnerable groups. This could enable the development of a more sophisticated calculation of accessibility.

Additionally, delving deeper into the characteristics of urban amenities that can act as deterrents or attractors is essential. For example, in the case of education, the quality of education is important when deciding which educational institution to attend or to what extent groceries and markets promote food deserts. In this regard, refining these and other aspects will provide a comprehensive understanding of urban mobility and its impacts in the NCAT capital cities.

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Informed Consent Statement: Not applicable. The data used for the research were directly obtained from the institutions cited in the article and did not involve interviews or direct contact with individuals or animals, making it unnecessary to validate it through the institutional ethics committee.

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