Supplementary Information: Equity Principles Highlight Variations in Road Network Criticality

Jin Rui Yap[1†], Bramka Arga Jafino[1*†], and Trivik Verma[1*]

[1]Faculty of Technology, Policy and Management, Delft University of Technology, Delft, The Netherlands
[*]Corresponding authors. Email: b.a.jafino@tudelft.nl, t.verma@tudelft.nl
[†]These authors contributed equally to this work.

1 Equity-weighted OD matrix calculation

The calculation of equity-weighted Origin-Destination (OD) matrix involves two step. In the first step, an original OD matrix is calculated based on the population of each region, which in this case is the level-2 administrative region in each country. In the second step, the original OD matrix is transformed into an equity-weighted OD matrix. The transformation function depends on the distributive principle, which follows Jafino (2021).

Step 1 – Calculation of original OD matrix The formulation of the original OD matrix follows a standard distance decay gravity model de Dios Ortúzar and Willumsen (2011). In particular, transport demand between two zones is calculated by:

$$d_{ij} = Q_i * X_j * F_{ij}, \tag{1}$$

where d_{ij} is the transport demand between zone i and j, Q_i is the production potential of zone i, X_j is the attraction potential of zone j, and F_{ij} is the deterrence factor between the two zones. We use the population density of each zone as the production and attraction potential of that zone. The deterrence function is calculated by:

$$F_{ij} = e^{-C_{ij}}, \tag{2}$$

with C_{ij} being the normalized distance between zone i and j, calculated as the ratio of the shortest-path distance between zone i and j: (c_{ij}) and the longest shortest-path distance between all pairs of zones,

$$C_{ij} = \frac{c_{ij}}{\max\limits_{i,j \in OD}\{c_{ij}\}}, \tag{3}$$

Step 2 – Transformation into equity-weighted OD matrix Once all transport demands d_{ij} have been calculated for all pairs of regions, they are further transformed into equity-weighted OD matrix. The transformation functions for the three different principles are provided in the table below.

Table 1: Transformation functions for calculating equity-weighted OD matrix, adapted from (Jafino, 2021)

Distributive principle	**School of thought behind the principle**	**Description**	**Transformation functions**
Proportionality	Utilitariansm	Consideration to each region is proportional to the level of the attribute size of the region	$d^e_{ij} = d_{ij}$
Equality	Egalitarianism	Equal consideration to all regions regardless of the size of their attributes	$d^e_{ij} = d_{ij}/d_{ij}$
Equalization	Rawlsian Maximin	Minimizing inequality among regions - consideration to each region is inversely proportional to the size of the region's attributes relative to all other regions	$d^e_{ij} = d_{ij} * (w_i/\bar{w})^{-\delta} * (w_j/\bar{w})^{-\delta}$; $\bar{w} = \frac{\sum_{i \in OD} w_i}{\lvert OD \rvert}$

where d^e_{ij} is equity-weighted transport demand between the two zones, w_i is the attribute level/size of zone i, which is subject to be equalized, $\bar{w}$ is the average attribute level/size across all zones, and δ is the inequality aversion factor. The higher the factor, the more weights attached to regions with smaller attribute level/size, signaling a higher preference for inequality aversion. We took into account three values for this factor (0.5, 1, and 2), but focused our reporting on $\delta = 1$.

The equalization principle requires a weighting variable which wants to be equalized. In this study, we consider two weighting variables: population and GDP. For the former, higher weight will be given to transport demand originating from and coming to less populated regions. This implies giving higher emphasis on accessibility to rural areas. For the latter, higher weight will be given to transport demand originating from and coming to less wealthy regions, implying higher emphasis on economically worse-off regions.

2 Tables

Table 2: Assumed travel speeds based on type of transportation link on OpenStreetMaps

Road link	**Travel speed (km/h)**
Motorway	80
Motorway link	65
Trunk	60
Trunk link	50
Primary	50
Primary link	40
Secondary	40
Secondary link	30
Tertiary	30
Tertiary link	20
Unclassified	20
Residential	20

Table 3: Key characteristics of countries selected for analysis

Country	**Income classification**	**No. of regions**	**OSM network length (km)**	**Population**[1]	**GDP per capita**[2]
Algeria	Upper middle income	1,504	160,455	44,122,118	13,809
Belarus	Upper middle income	118	133,600	9,161,834	16,579
Bolivia	Lower middle income	95	76,783	11,843,702	6,581
Brazil	Upper middle income	5,504	1,012,788	206,884,114	10,757
Cameroon	Lower middle income	58	68,711	28,175,049	2,942
Central African Republic	Low income	51	32,371	5,391,432	565
Colombia	Upper middle income	1,065	96,616	63,236,155	13,694
Congo	Lower middle income	48	17,633	4,044,797	6,029
Guinea	Low income	34	38,487	12,380,007	1,141
Haiti	Low income	41	6,306	14,397,485	1,658
Honduras	Lower middle income	293	18,921	8,705,064	4,373
Mali	Low income	50	49,739	23,264,260	2,287
Morocco	Lower middle income	54	95,236	35,478,460	6,390
Myanmar	Lower middle income	63	70,052	48,484,061	4,866
Nepal	Low income	14	28,929	35,480,280	2,173
Nicaragua	Lower middle income	139	12,074	6,871,310	3,686
Syria	Low income	60	79,329	26,829,339	3,817
Thailand	Upper middle income	928	210,124	75,001,327	9,773
Tunisia	Lower middle income	268	40,685	11,733,625	10,729
Ukraine	Lower middle income	629	240,383	43,765,204	6,283
Vietnam	Lower middle income	710	135,690	99,482,962	4,650
Yemen	Low income	333	33,848	30,286,382	4,737

[1] National population size values from (Worldpop) gridded dataset (Lloyd, Sorichetta, & Tatem, 2017).

[2] National (2015) GDP per capita values from gridded dataset by Kummu, Taka, and Guillaume (2018).

3 Criticality rankings

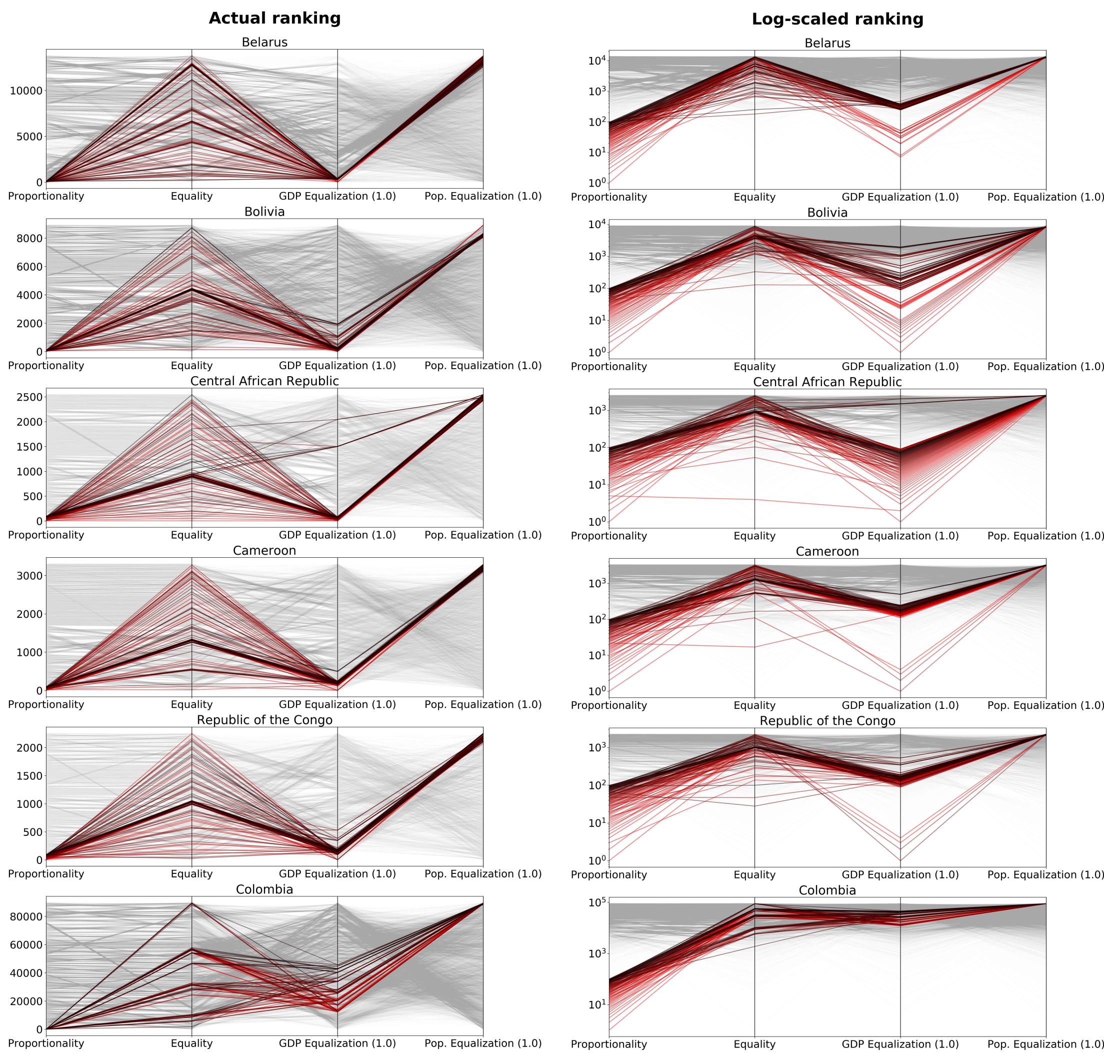

Figure 1: Criticality rankings based on different equity principles for six countries (Belarus, Bolivia, Central African Republic, Cameroon, Republic of the Congo, and Colombia). Highlighted in red and black are the top 100 most critical links in each country based on the proportionality principle. The grey lines indicate the remaining links in the network. We present the rankings in both linear (left) and log scales (right) to show the breadth and depth of change from one principle to another.

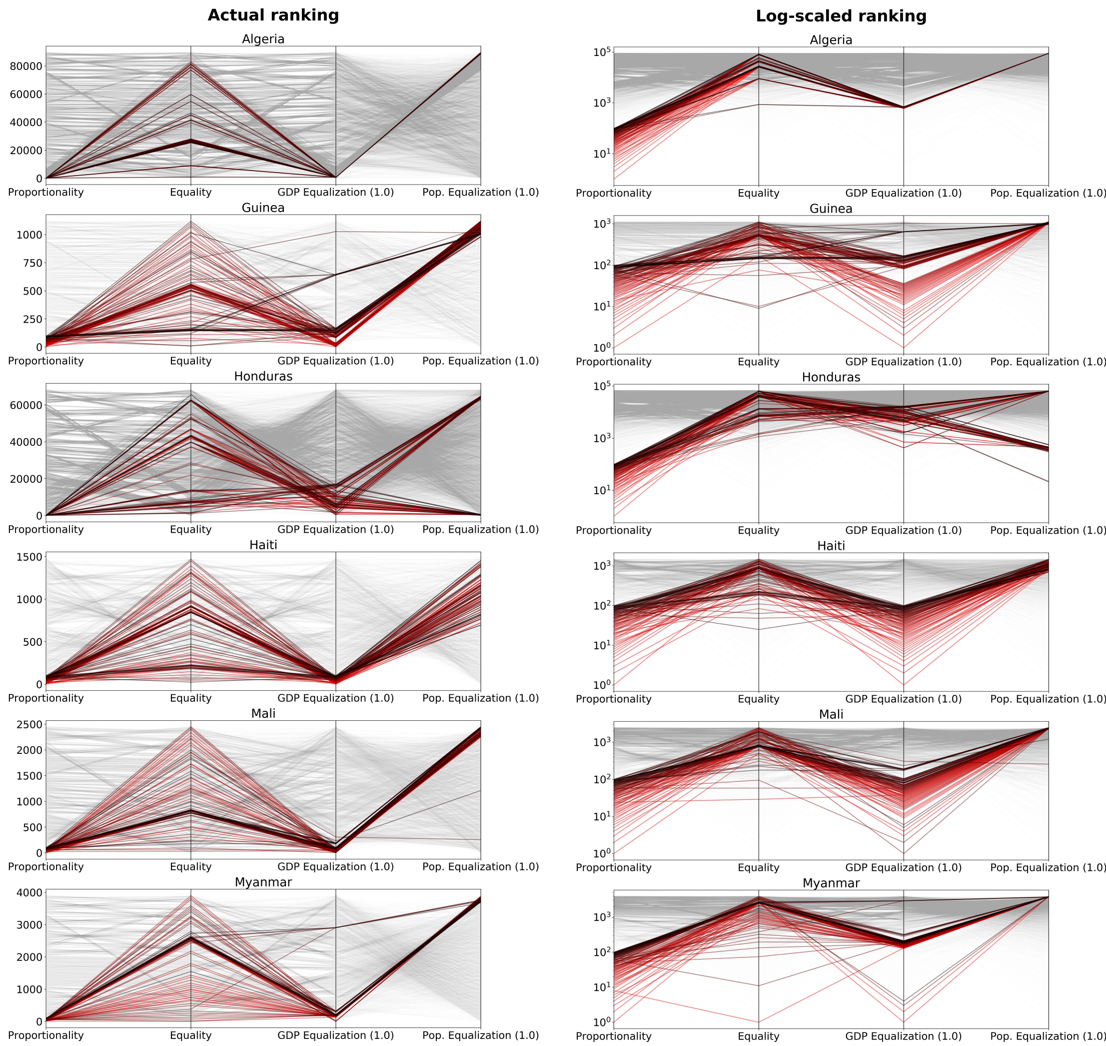

Figure 2: Criticality rankings based on different equity principles for six countries (Algeria, Guinea, Honduras, Haiti, Mali, and Myanmar). Highlighted in red and black are the top 100 most critical links in each country based on the proportionality principle. The grey lines indicate the remaining links in the network. We present the rankings in both linear (left) and log scales (right) to show the breadth and depth of change from one principle to another.

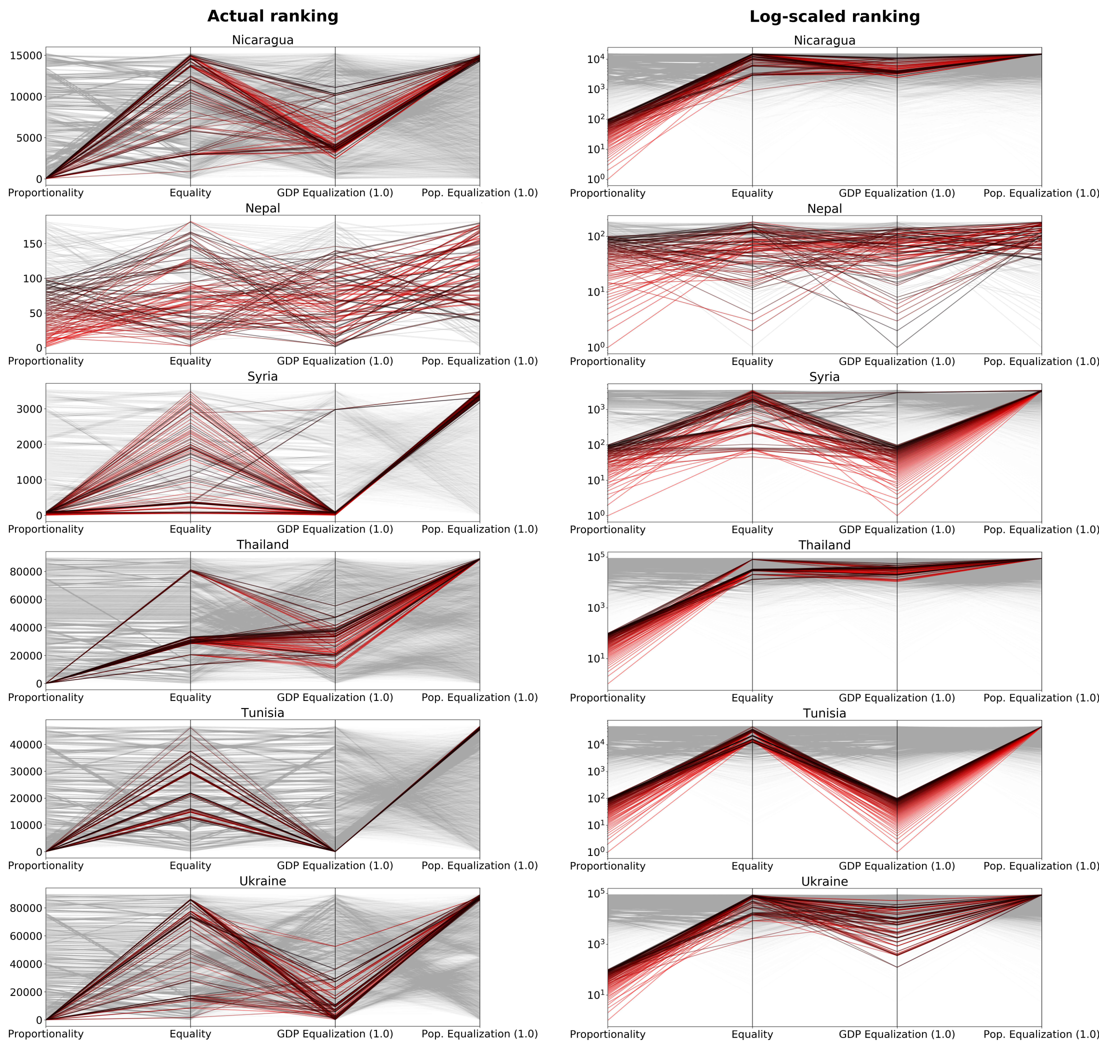

Figure 3: Criticality rankings based on different equity principles for six countries (Nicaragua, Nepal, Syria, Thailand, Tunisia, and Ukraine). Highlighted in red and black are the top 100 most critical links in each country based on the proportionality principle. The grey lines indicate the remaining links in the network. We present the rankings in both linear (left) and log scales (right) to show the breadth and depth of change from one principle to another.

4 Spatial distribution of critical links

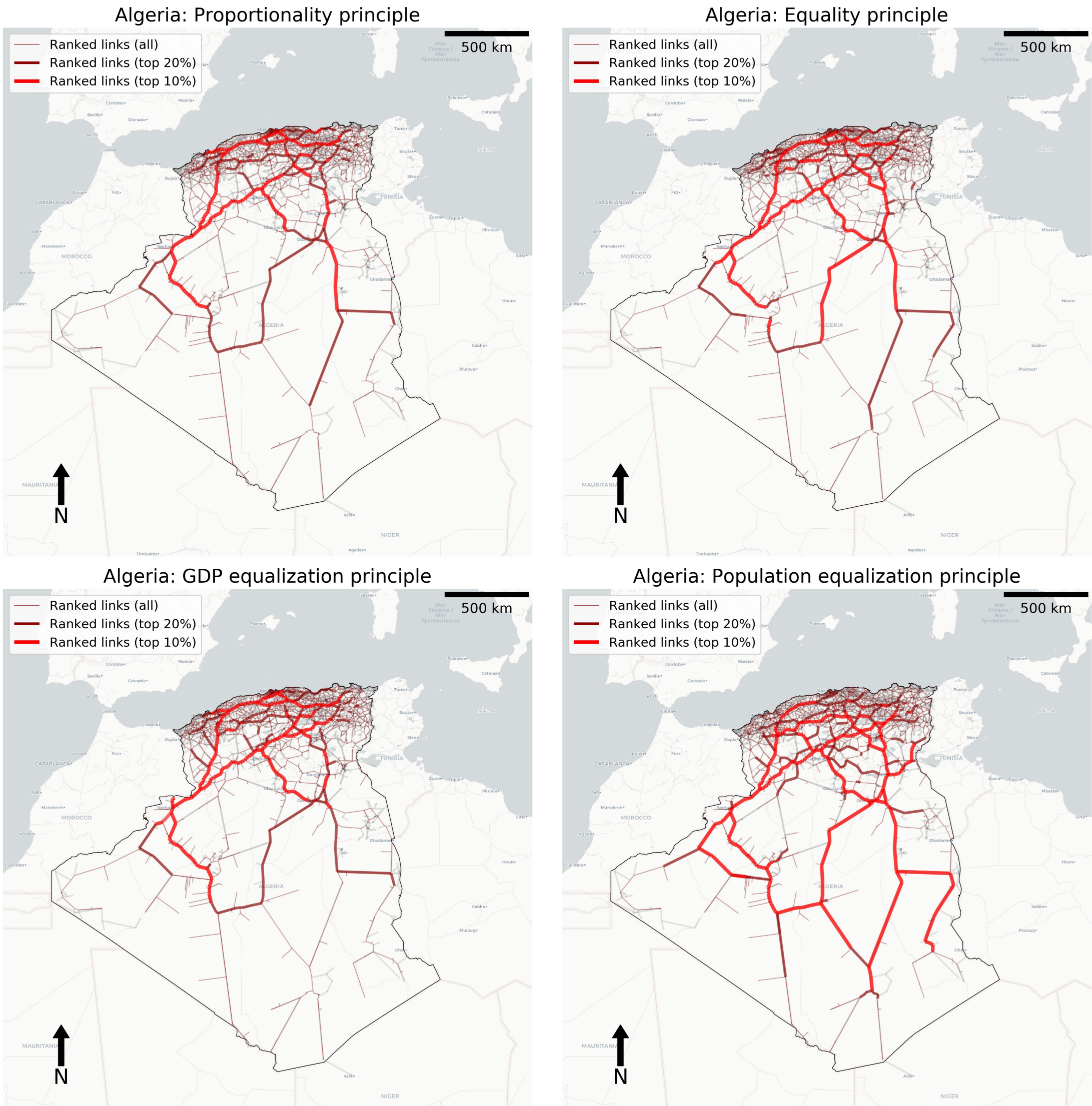

Figure 4: Criticality of the road Segments in Algeria. Thicker lines imply higher criticality.

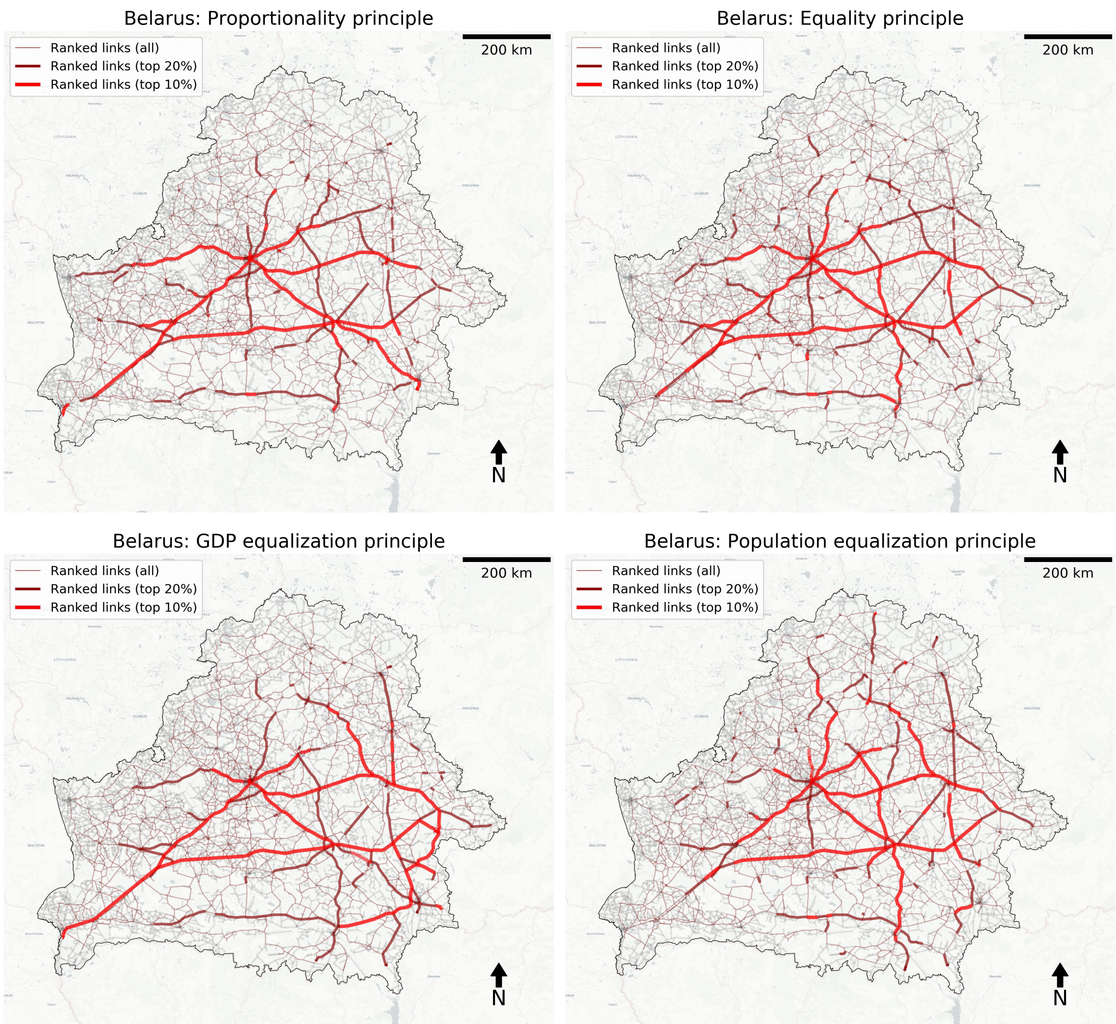

Figure 5: Criticality of the road Segments in Belarus. Thicker lines imply higher criticality.

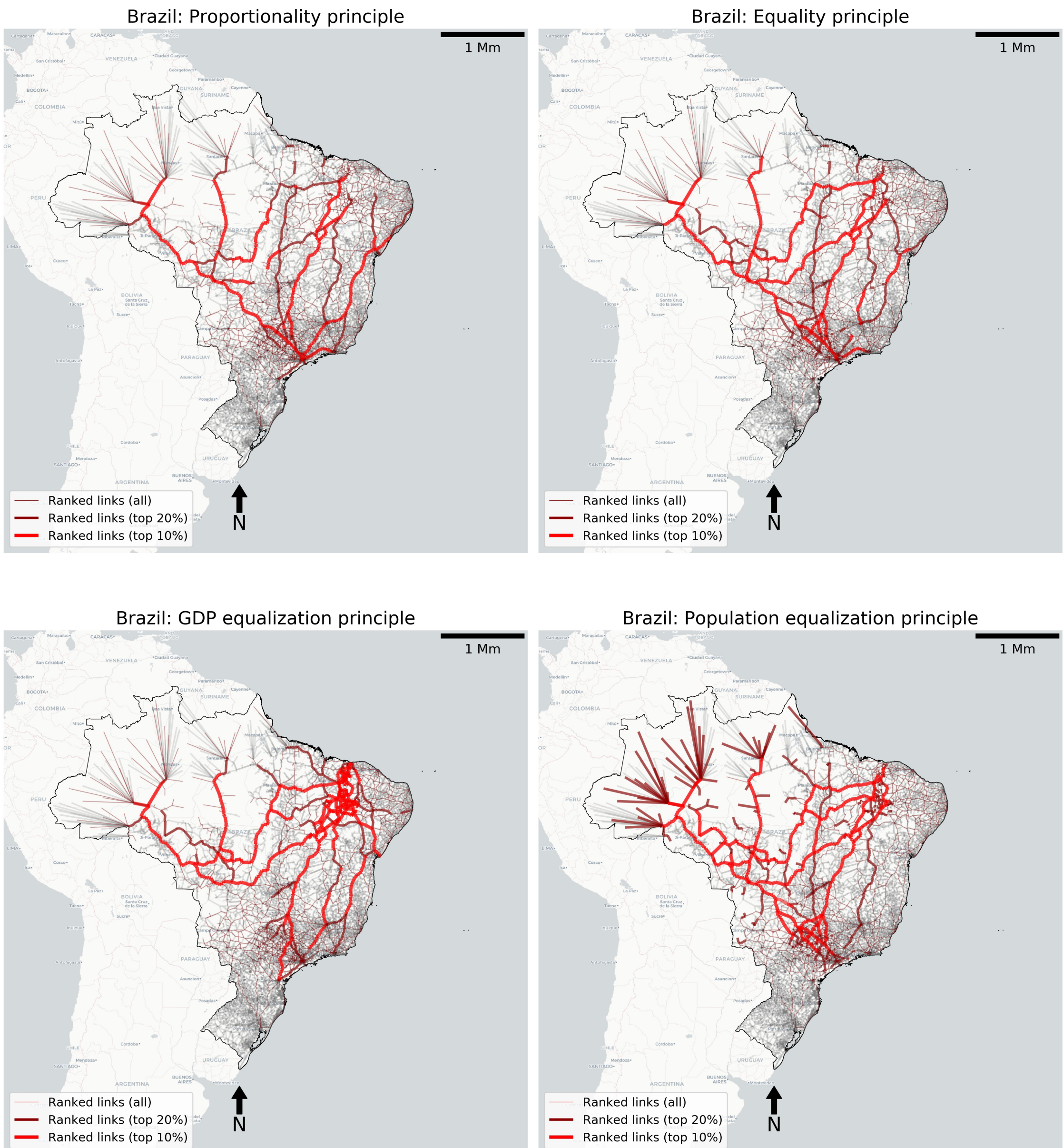

Figure 6: Criticality of the road Segments in Brazil. Thicker lines imply higher criticality.

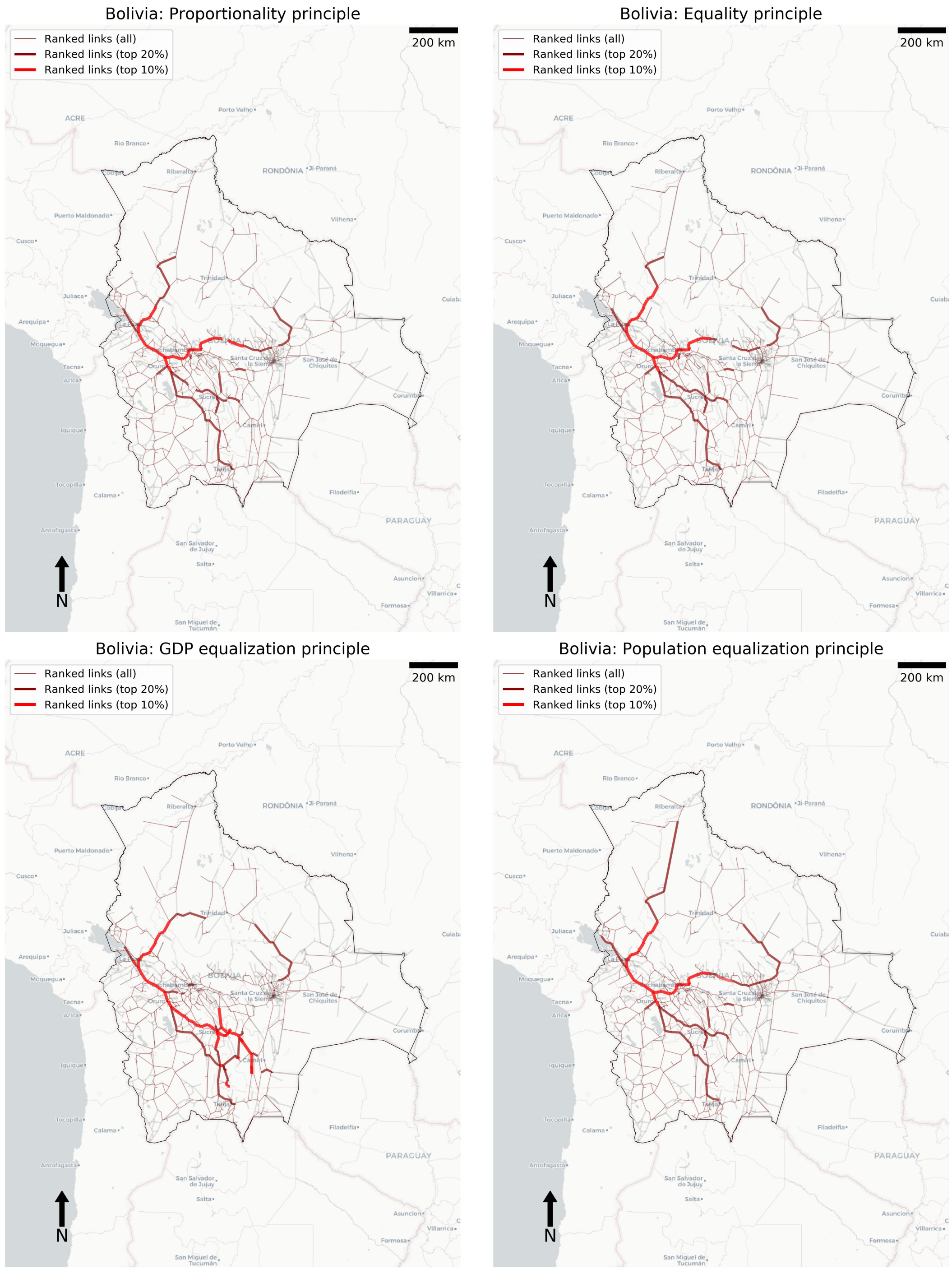

Figure 7: Criticality of the road Segments in Bolivia. Thicker lines imply higher criticality.

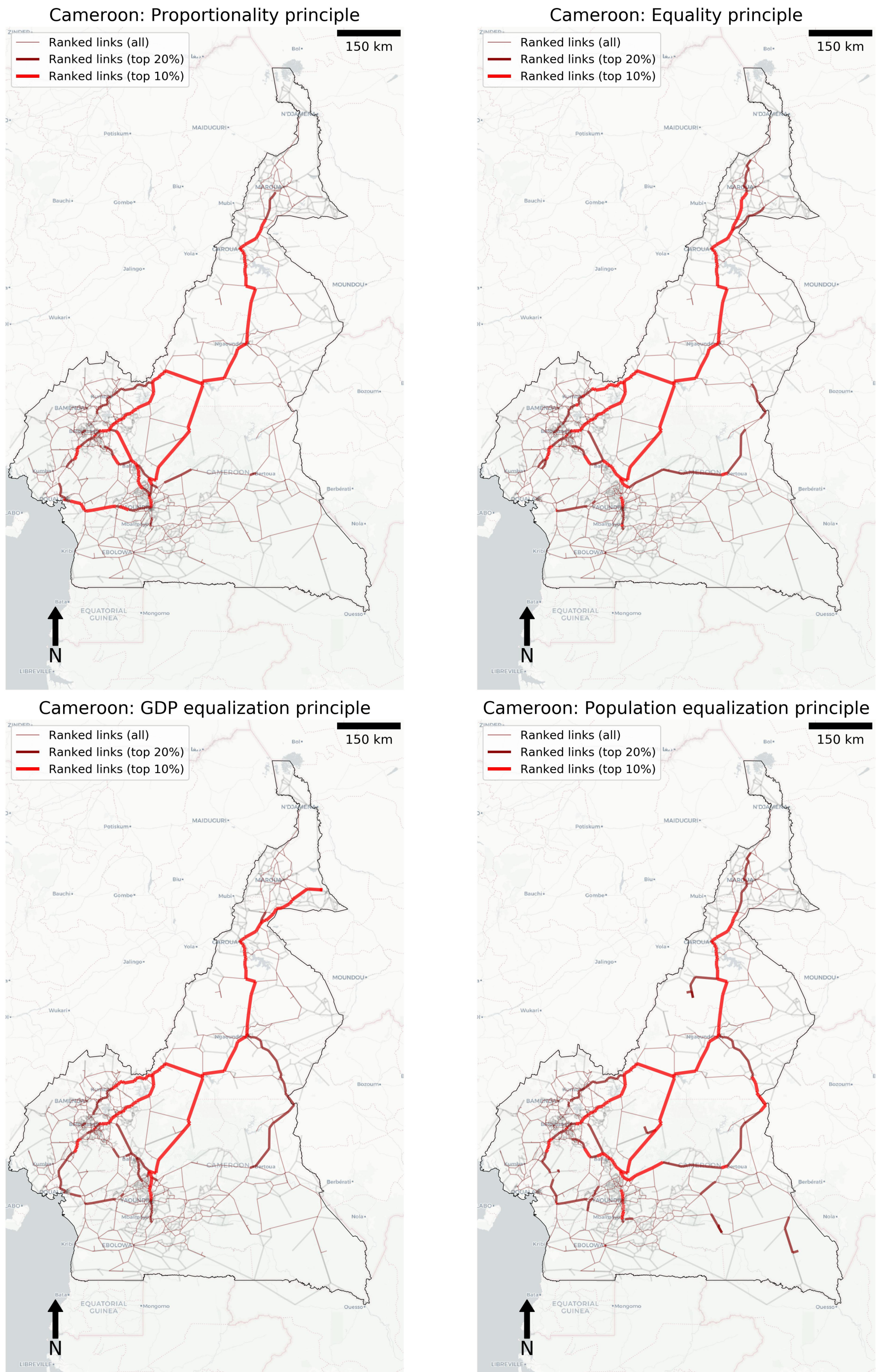

Figure 8: Criticality of the road Segments in Cameroon. Thicker lines imply higher criticality.

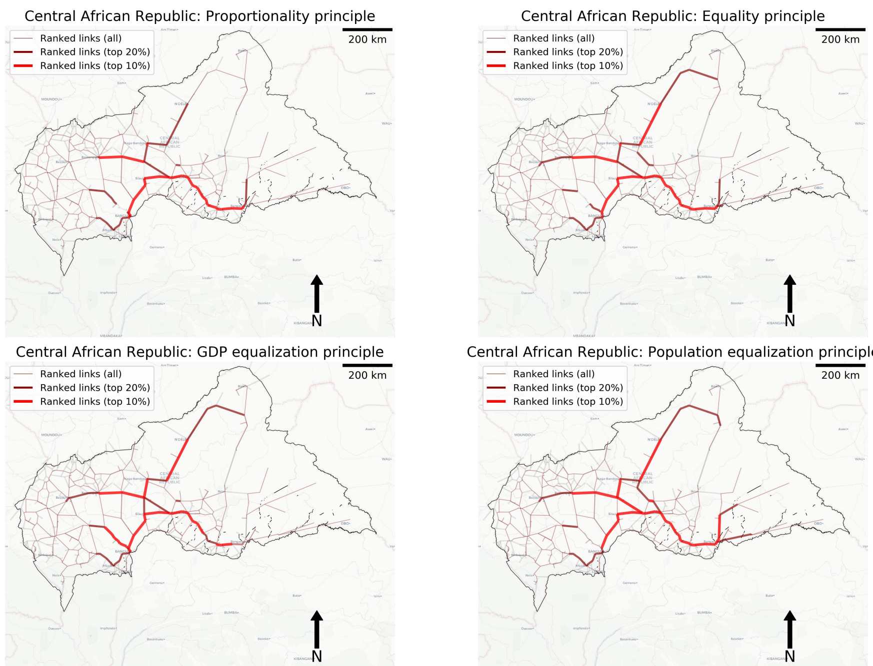

Figure 9: Criticality of the road Segments in the Central African Republic. Thicker lines imply higher criticality.

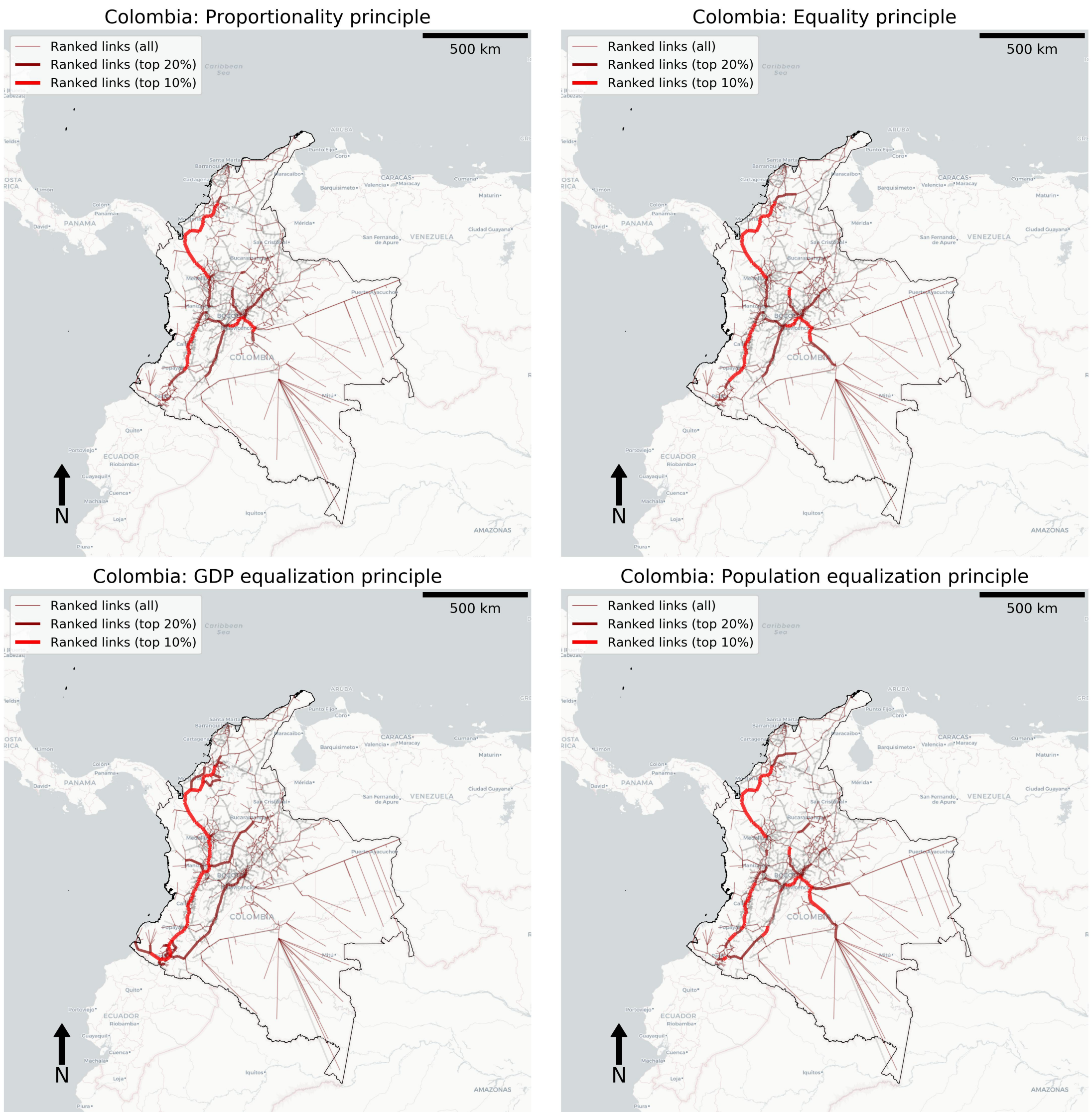

Figure 10: Criticality of the road Segments in Colombia. Thicker lines imply higher criticality.

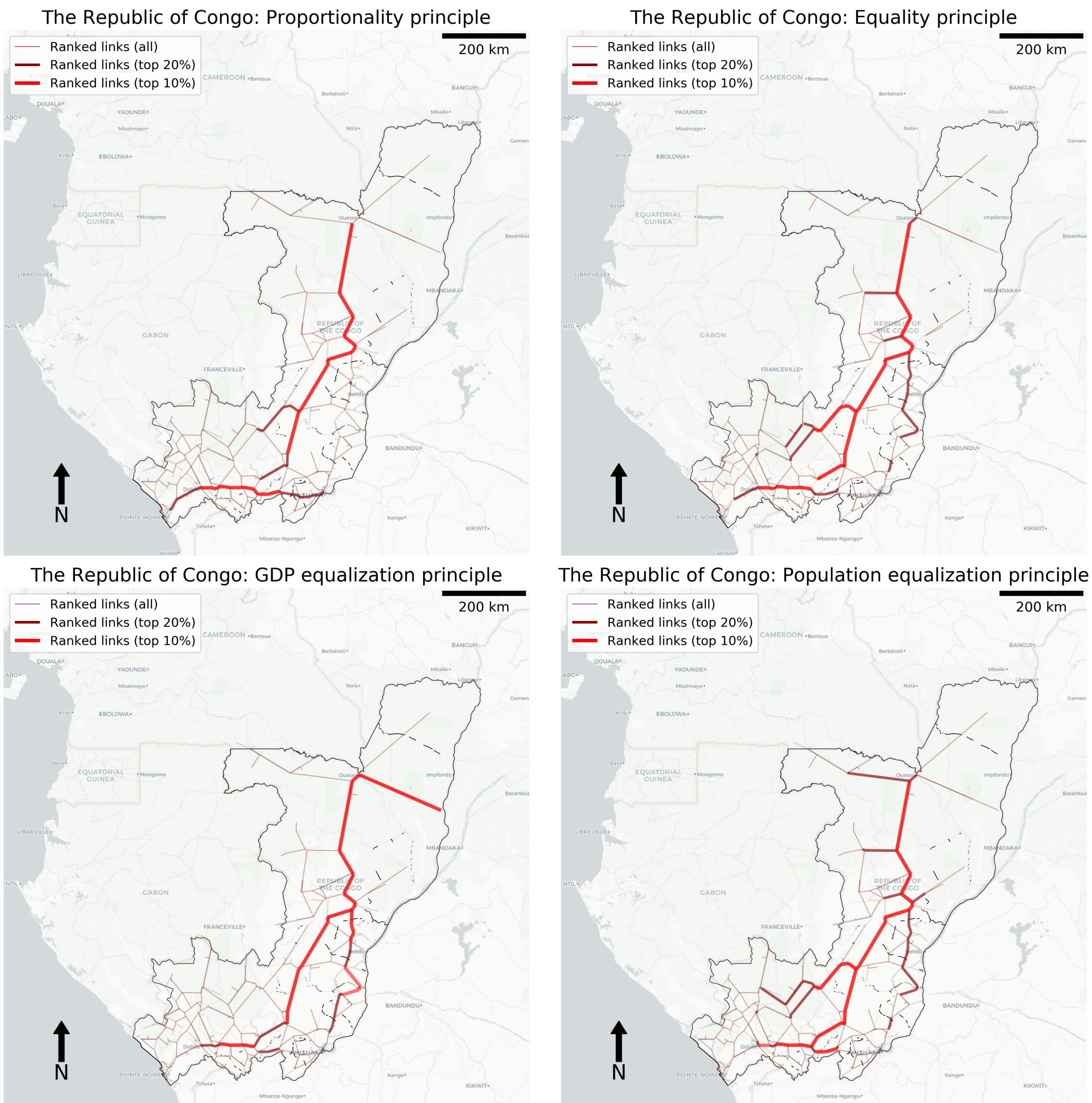

Figure 11: Criticality of the road Segments in the Republic of Congo. Thicker lines imply higher criticality.

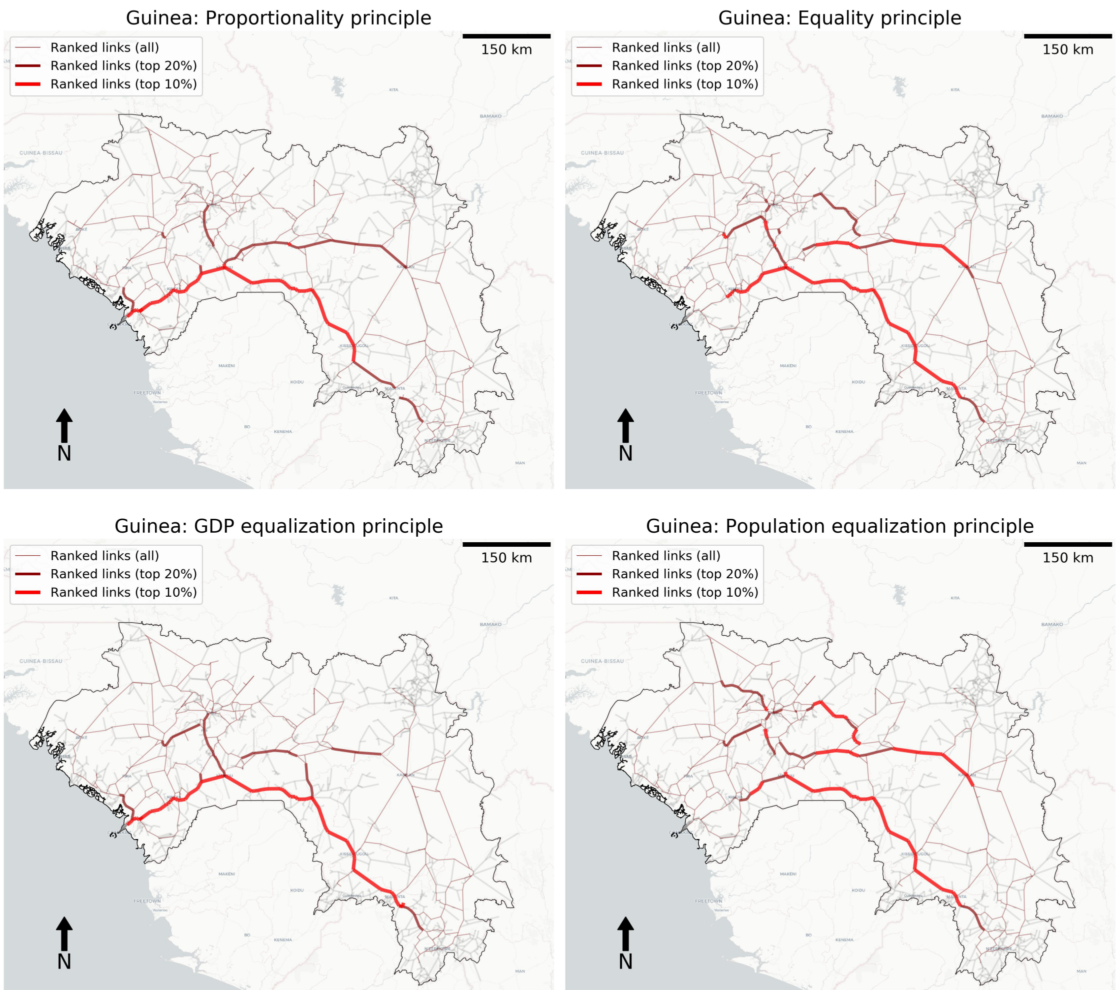

Figure 12: Criticality of the road Segments in Guinea. Thicker lines imply higher criticality.

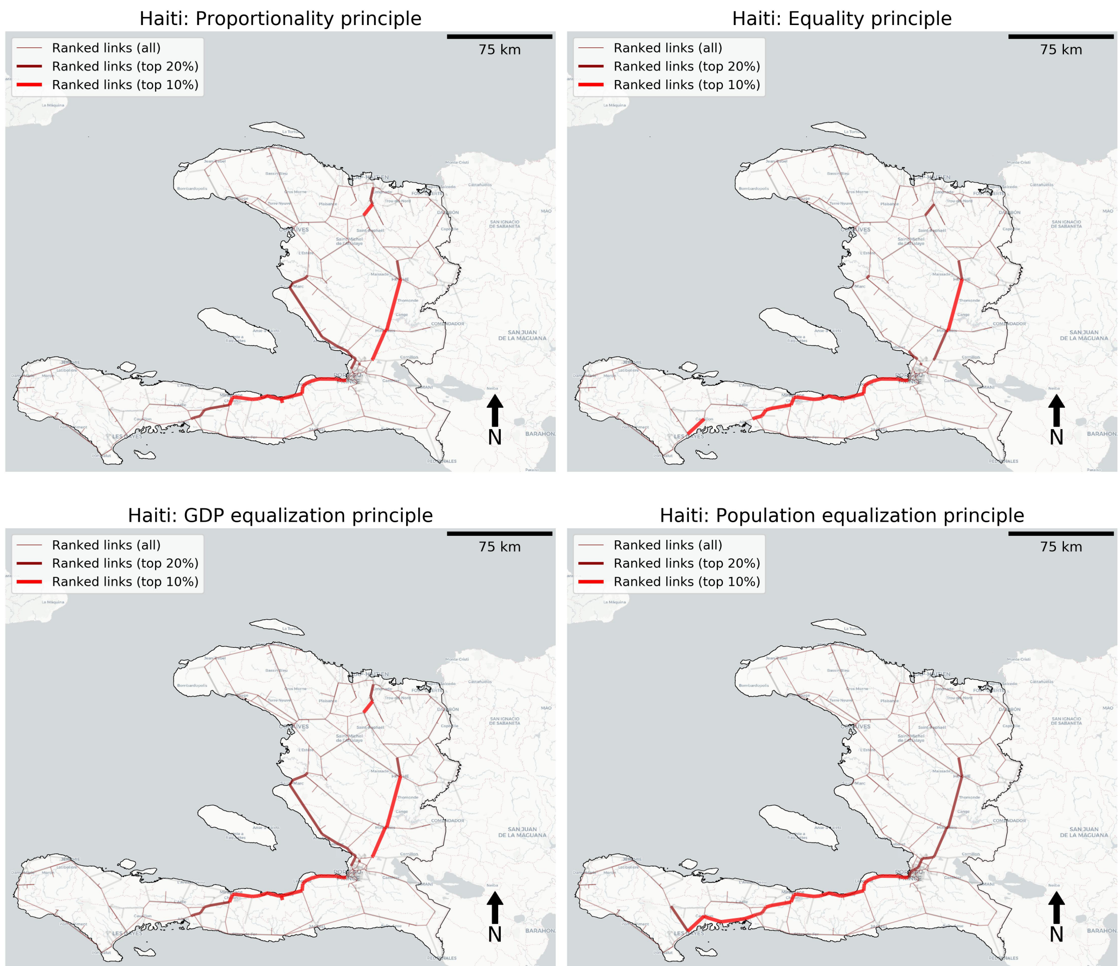

Figure 13: Criticality of the road Segments in Haiti. Thicker lines imply higher criticality.

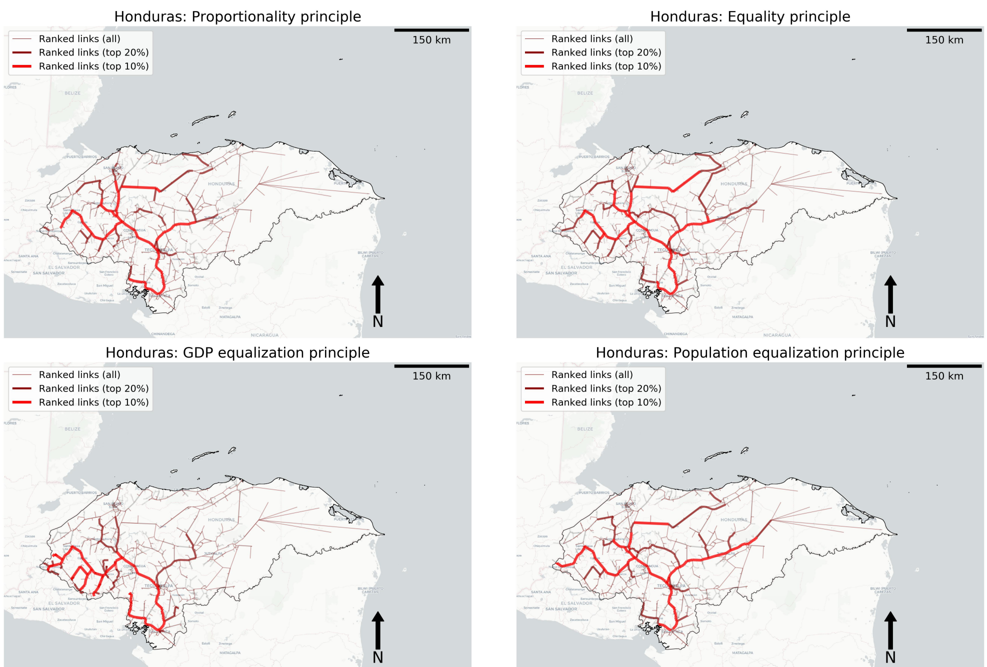

Figure 14: Criticality of the road Segments in Honduras. Thicker lines imply higher criticality.

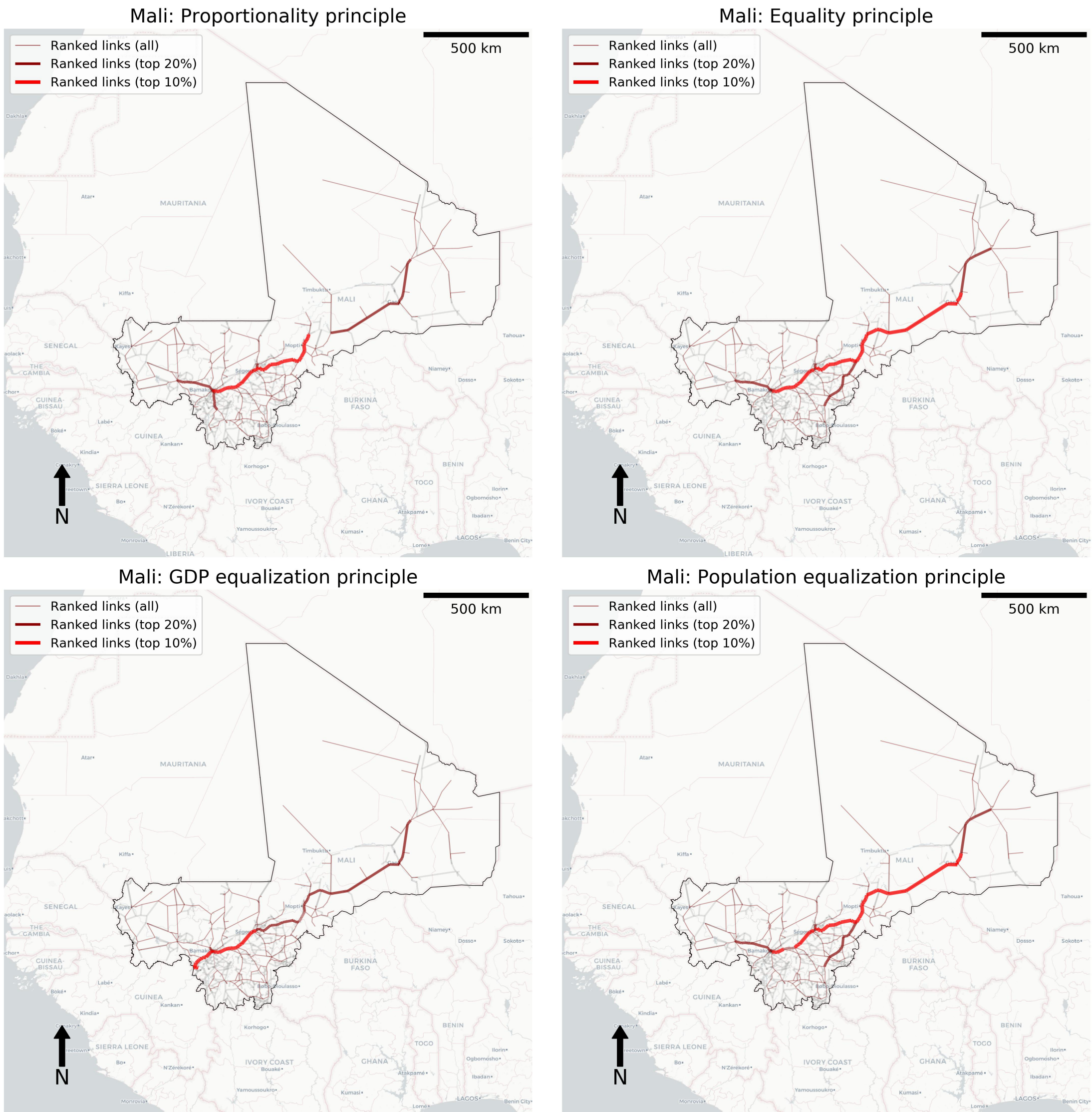

Figure 15: Criticality of the road Segments in Mali. Thicker lines imply higher criticality.

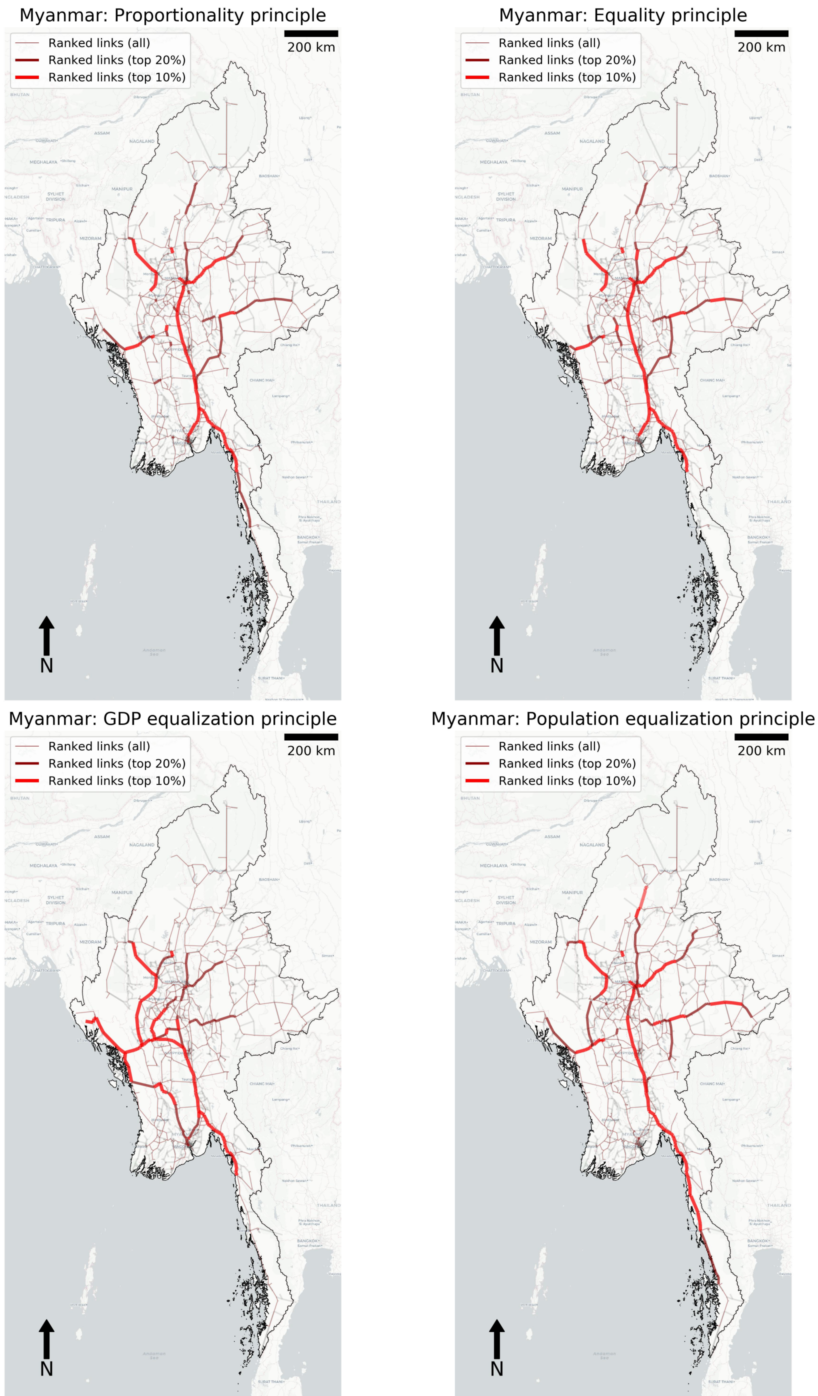

Figure 16: Criticality of the road Segments in Myanmar. Thicker lines imply higher criticality.

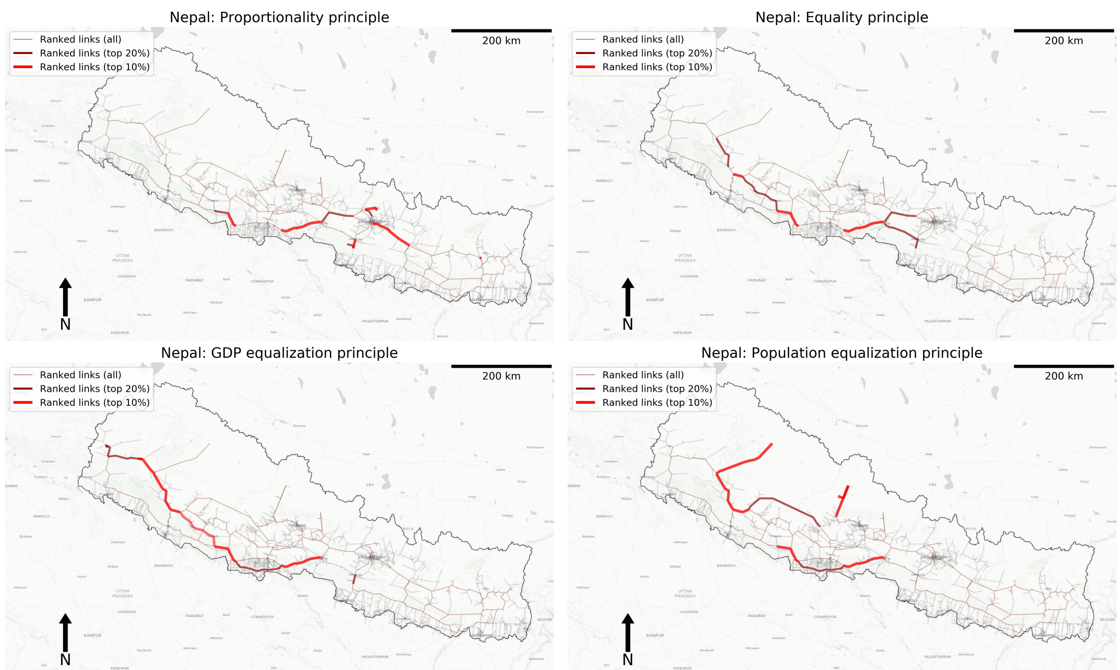

Figure 17: Criticality of the road Segments in Nepal. Thicker lines imply higher criticality.

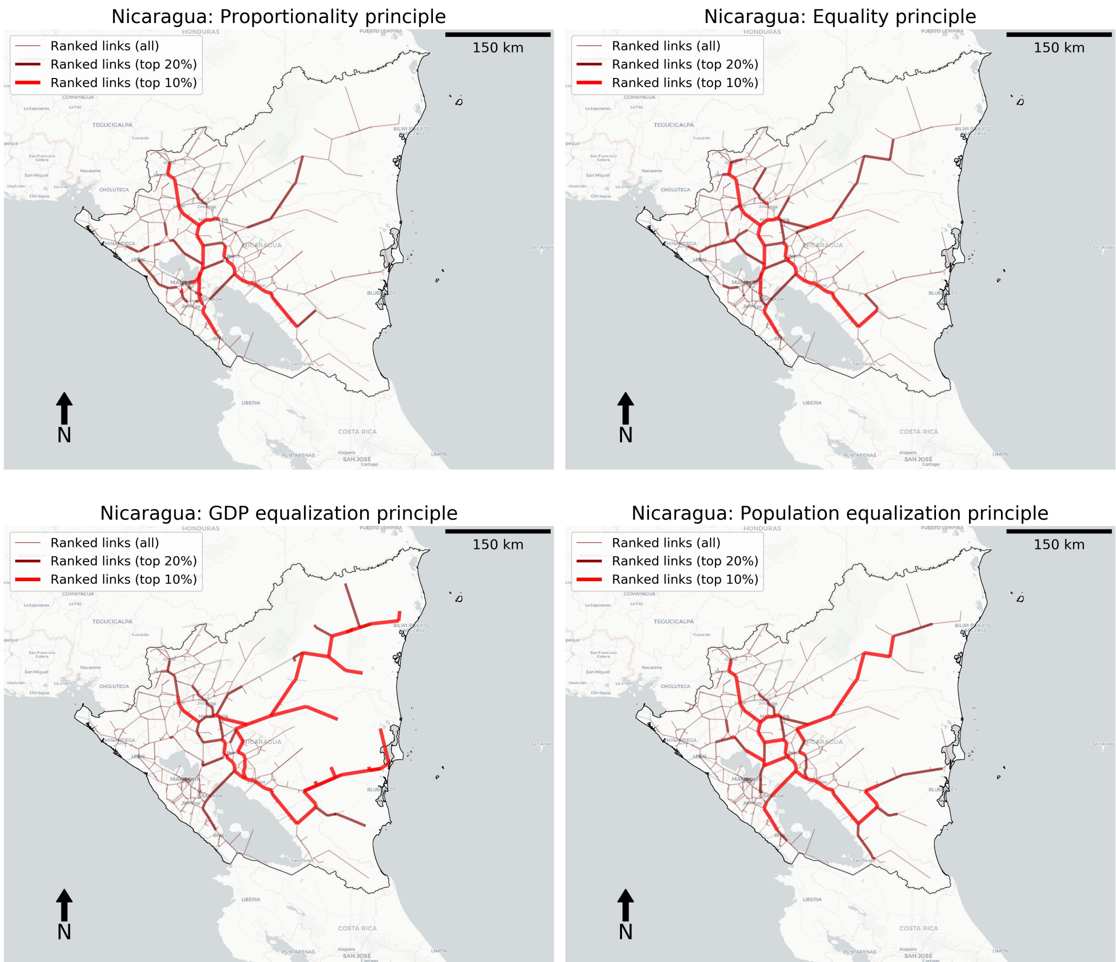

Figure 18: Criticality of the road Segments in Nicaragua. Thicker lines imply higher criticality.

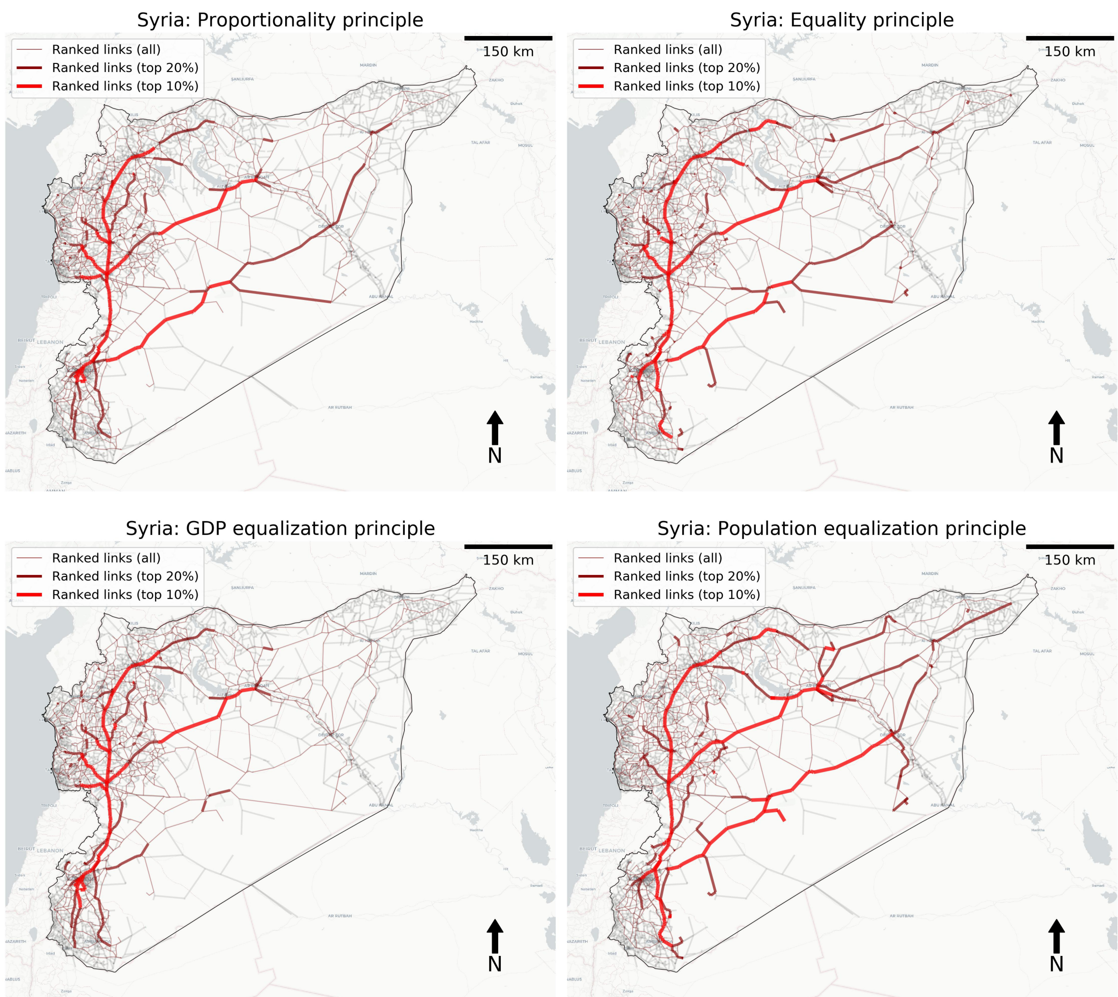

Figure 19: Criticality of the road Segments in Syria. Thicker lines imply higher criticality.

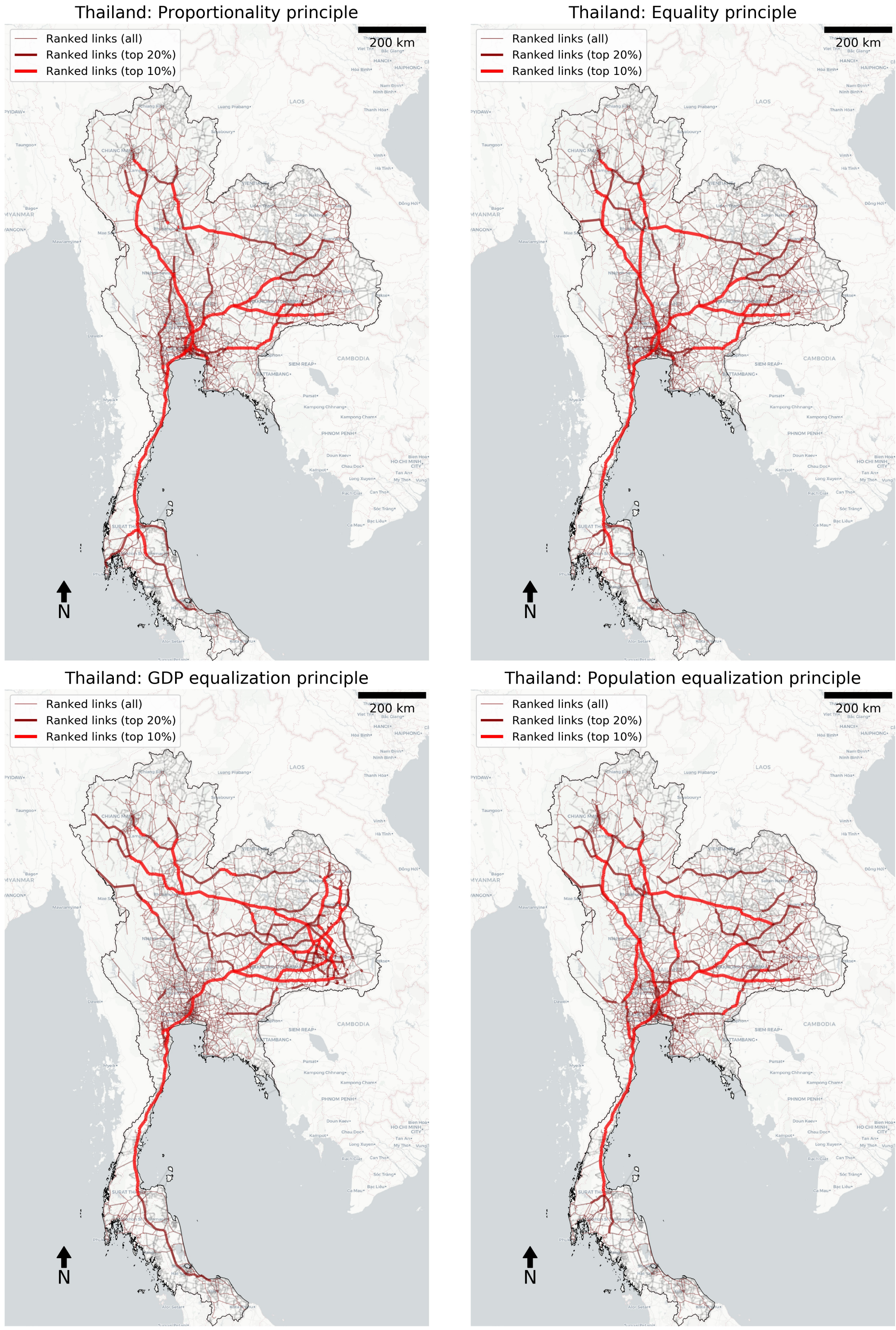

Figure 20: Criticality of the road Segments in Thailand. Thicker lines imply higher criticality.

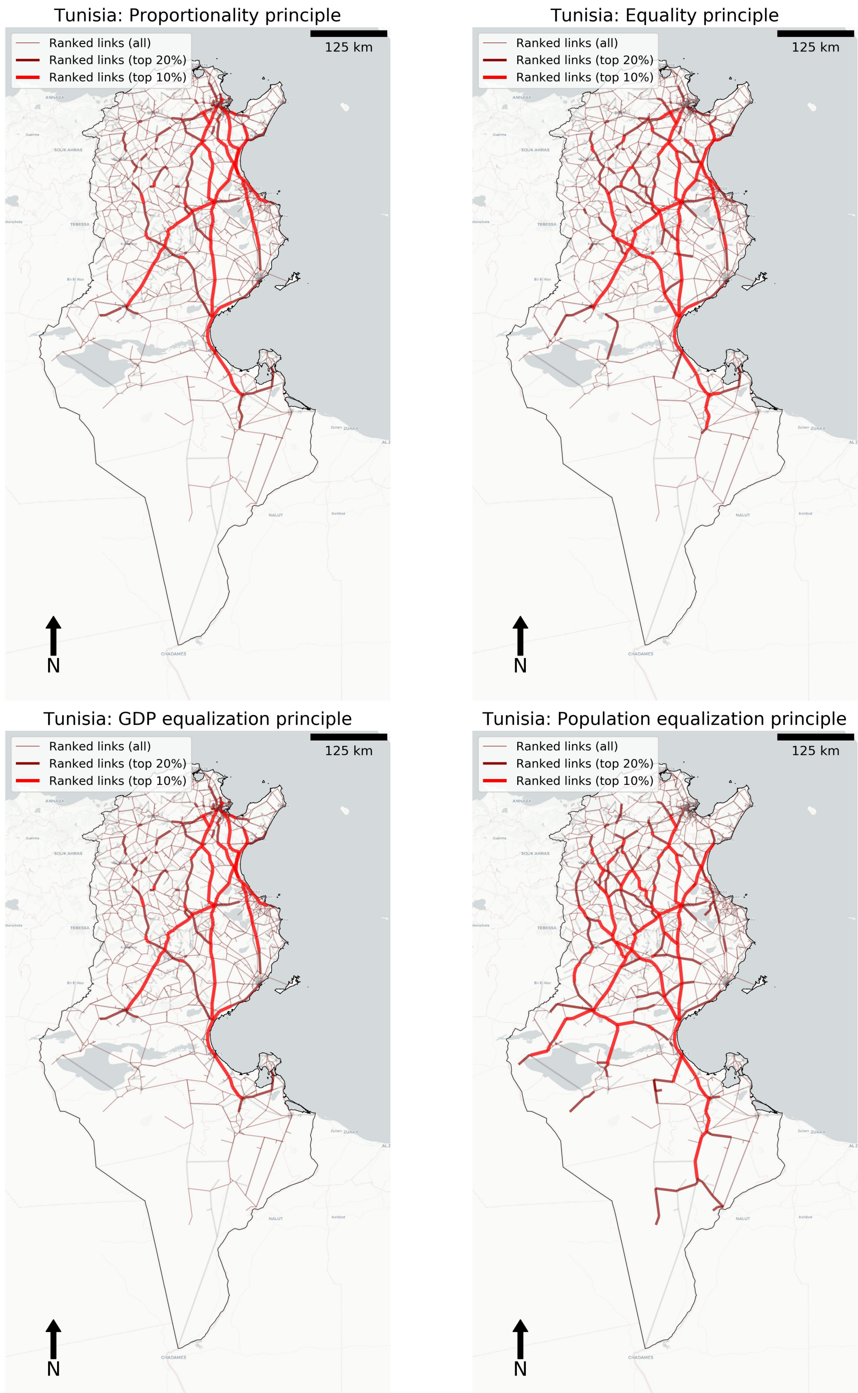

Figure 21: Criticality of the road Segments in Tunisia. Thicker lines imply higher criticality.

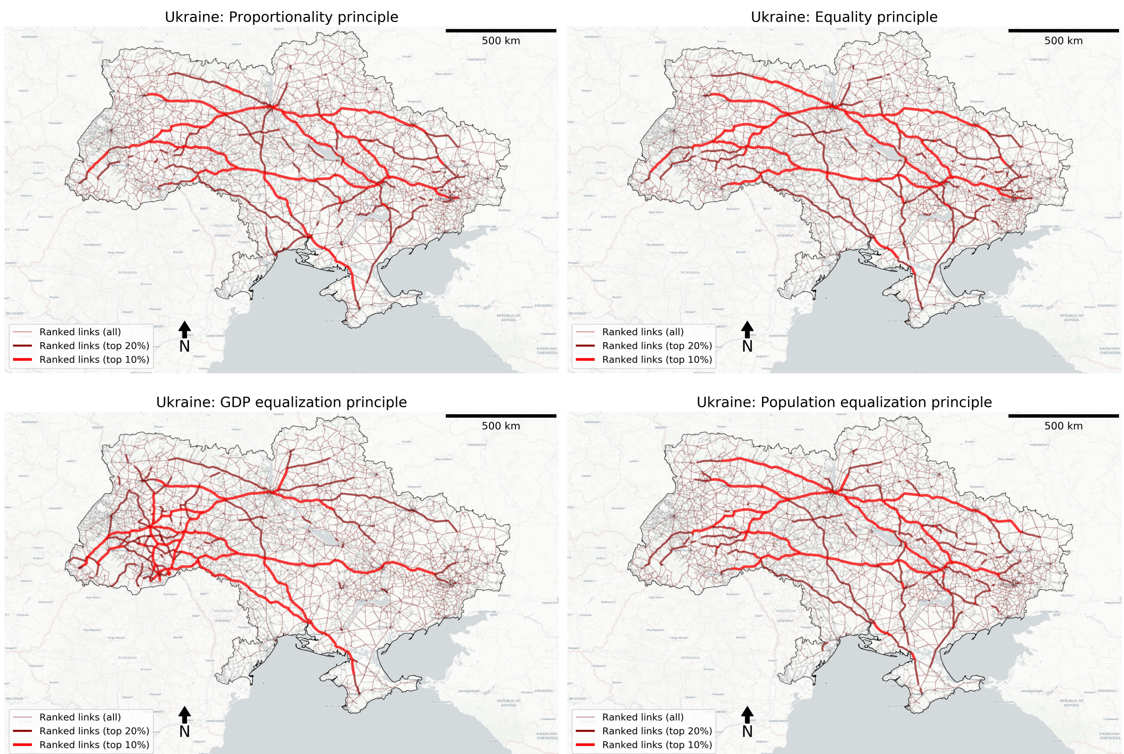

Figure 22: Criticality of the road Segments in Ukraine. Thicker lines imply higher criticality.

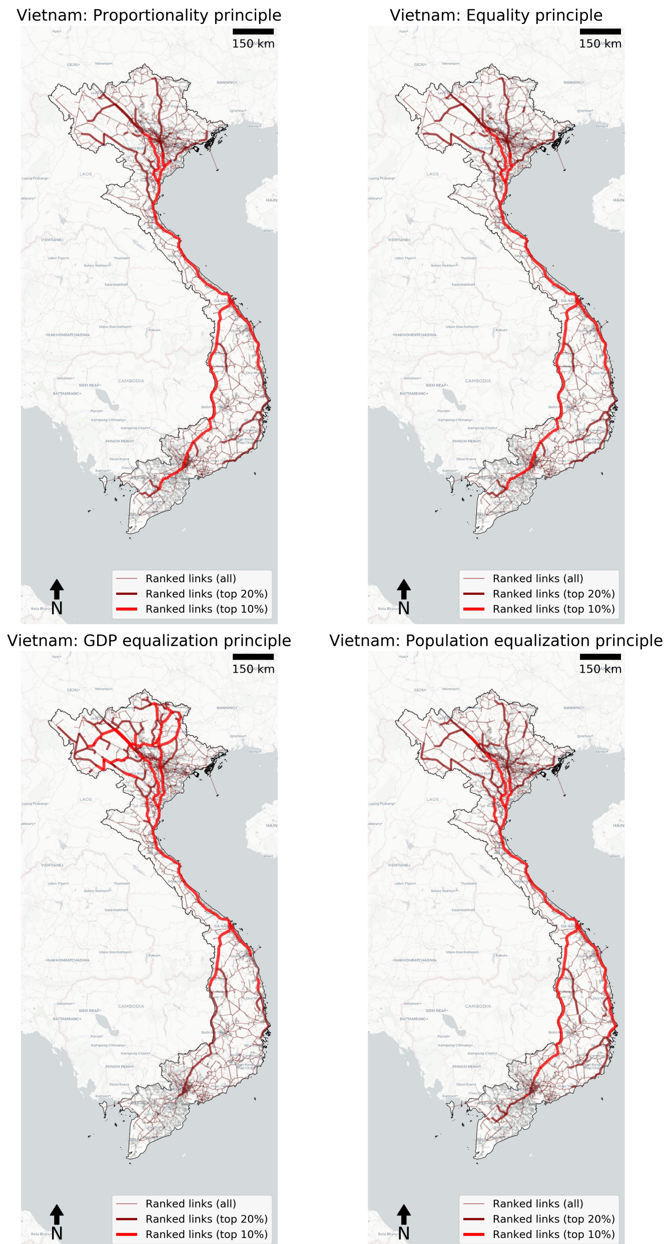

Figure 23: Criticality of the road Segments in Vietnam. Thicker lines imply higher criticality.

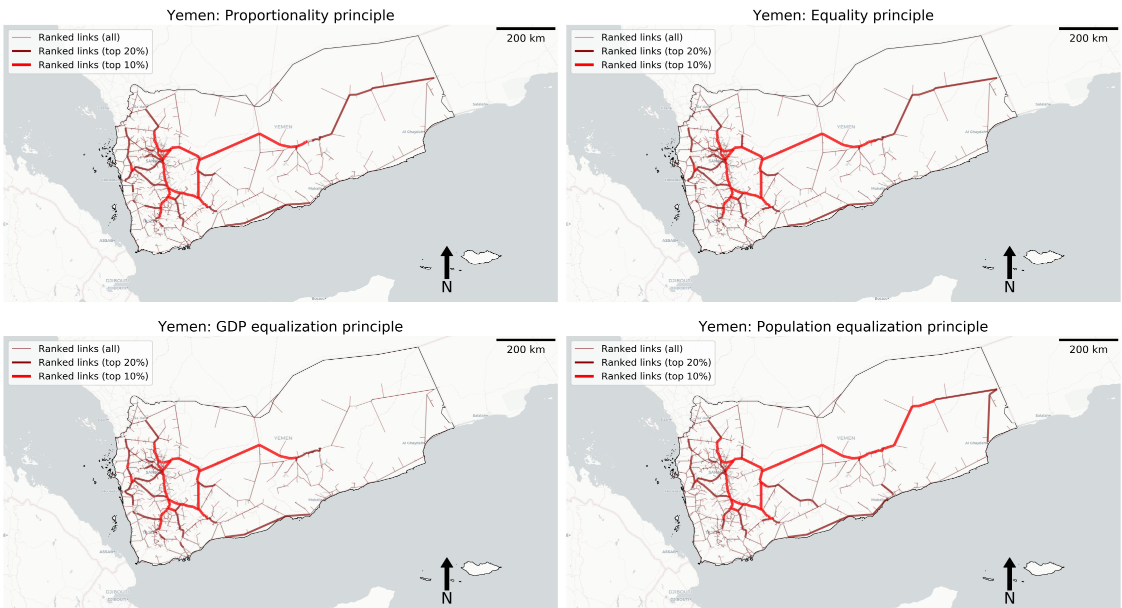

Figure 24: Criticality of the road Segments in Yemen. Thicker lines imply higher criticality.

References

de Dios Ortúzar, J., & Willumsen, L. G. (2011). *Modelling transport.* John wiley & sons.

Jafino, B. A. (2021). An equity-based transport network criticality analysis. *Transportation Research Part A: Policy and Practice*, *144*, 204-221. doi: https://doi.org/10.1016/j.tra.2020.12.013

Kummu, M., Taka, M., & Guillaume, J. H. (2018). Gridded global datasets for gross domestic product and human development index over 1990–2015. *Scientific data*, *5*(1), 1–15. doi: https://doi.org/10.1038/sdata.2018.4

Lloyd, C. T., Sorichetta, A., & Tatem, A. J. (2017). High resolution global gridded data for use in population studies. *Scientific data*, *4*(1), 1–17. doi: https://doi.org/10.1038/sdata.2017.1