Supplementary Information

to

How much infrastructure is required to support decent mobility for all? An exploratory assessment

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1 Mobility indicators

Following the conceptualization of ‘transport poverty’ different indicators for mobility can be grouped by the assessed aspects of affordability, mobility (activity) and accessibility as well as exposure to externalities. Table S 1 lists an adapted and extended selection of mobility indicators by (Lowans et al., 2021) and (Lucas et al., 2016) ad other sources (see last column). The list is not all-encompassing, as many other studies also list indicators that are slightly different but overlapping, very specific and thus not suitable for representing mobility services or important aspects of those or do not fit into the selected dimensions of mobility as they cover other aspects such as infrastructural provision or general externalities. Examples are vehicle or passenger counts, quality assessments of infrastructure or certain transport-related emission levels. A complete review of all existing transport measures is beyond the scope of this article. For example, a set of 14 ‘Sustainable Transportation Performance Indicators’ (STPI) has been developed to measure progress of sustainable development. These cover impacts on environment and health (PJ of fossil energy used, GHG emissions, total emissions, road fatalities and injuries), transport activity (motorized distances travelled, motorized movement of freight, share of motorized individual travel, vehicle-kilometres), intensity of land use by transport per capita, length of paved road network, affordability (cost of transport relative to all household spending, urban transit fares) and environmental sustainability (energy and emission intensity of the road vehicle fleet), and have been evaluated for Canada for the period of 1990-2000 (Gilbert et al., 2002). A further compilation of sustainable transport indicators used in the US can for example be found in Zhou (2012), indicators used in the European Union are listed in Janic (2006), further sustainable transport and performance indicators are listed in Gudmundsson (2007).

From all indicators compiled in Table S 1, many measure specific dimensions of mobility, but hardly any of them can be rolled out for a cross-national or global analysis for various reasons: They are often dependent on specific datasets which are not available or comparable in many regions or recent years, have not been validated in their impact on satisfactory mobility outcomes on a larger scale and most of them assess only one aspect of mobility and would need to be combined with complementary measures to assess overall mobility. Exceptions are widely used general counts of trips or travelled distances (p-km), the Rural Access Index and travel times to urban centres.

Table S 1: Indicators of mobility based on Lowans et al. 2021, adapted and extended by information from (Lucas et al., 2016) and others (see last column)

	Dimension	**Metric/Method (Threshold proposed)**	**Study area**	**Source**
Affordability	Household expenditure on transport	% of household expenditure on transport (10%)	UK	RAC Foundation 2012 (Lucas et al., 2007)
	Commuter fuel poverty	Income spent on work travel (10%)	Yorkshire, Humber, UK	(Lovelace and Philips, 2014)
	Car-related economic stress	(1) income after housing and running motor vehicle (60% of median) (2) income spent on running motor vehicle (twice of sample's median = 9.5%)	Great Britain	(Mattioli et al., 2016)
	Forced car ownership	Owning at least one car and difficulty to afford one of five items: rent, mortgage, household maintenance, energy, food; (one of five)	UK	(Mattioli, 2017)
	Motoring expenditure	Costs for a vehicle compared to median income	England, Wales (UK)	(Chatterton et al., 2018)
Mobility	Travel (incl. mode) choices	Choice of destination (e.g. which school) and travel mode	Slum residents in Nairobi, Kenya (2004)	(Salon and Gulyani, 2010)
	Activity space	Standard distance circle, total distance travelled and number of geographic locations visited, number of unique activity places	Hong Kong	(Tao et al., 2020)
	Trip generation	Number of trips	London (2001)	(Schmöcker et al., 2005)
	Trip distance	Distances travelled (person-kilometres)	Canadian urban centres (2001/2003)	(Morency et al., 2011)

	Duration of regular trips/commuting time	Time use of mobility, commuting time	UK (2008)	(McQuaid and Chen, 2012)
Accessibility	Accessibility index of employment opportunities	Accessibility of employment opportunities	Boston inner city (1990)	(Shen, 1998)
	Synthetic index of adequate service	Access to public transport (incl. expenditure, walking distance to the nearest stop, average travelling time and headway, reliability of service, security and safety)	Brazilian cities	(Gomide et al., 2005)
	Transport disadvantage	Availability/lack of public transport options	Melbourne	(Currie et al., 2010)
	Rural activity spaces	Transport activity spaces	Northern Ireland	(Kamruzzaman and Hine, 2012)
	Accessibility of services	Modelled travel times to key services (e.g. hospital, education, food shops, employment centres)	England/UK	(Department for Transport, 2014) (Lucas et al., 2007)
	Transit access to employment	Locations access by transit and car	Canada	(Allen and Farber, 2019)
	Spatial Accessibility Poverty		Northeast Brazil	(Benevenuto and Caulfield, 2020)
	Rural Access Index (from surveys / geospatial)	Accessibility of adequate roads from households	183 countries (different years btw. 1993 & 2019)	(Worldbank et al., 2016)
	Travel time to urban centres	Time to reach the closest urban centre by any mode of transport	Globally (2015)	(Nelson et al., 2019)
Exposure to externalities	Causalities of pedestrians	Number of (child) pedestrian causalities per 1,000	UK (2006)	(Lucas et al., 2007)
	Incidences of crime	Recorded incidences of crime on public transport	UK (2006)	(Lucas et al., 2007)
	"Safe walk" to key destinations	Percentage of residents living within 1,000m or 15 min "safe walk" to key destinations (e.g. health/educational facilities, food shops, post office etc.)	UK (2006)	(Lucas et al., 2007)
Composite measures	Composite risk of transport poverty	Income, distance to nearest bus/railway station, time to access essential goods and services by walking, cycling or public transport	UK	(Sustrans, 2012)
	Composite measure of financial resources, practices and conditions of mobility	Income level, fuel spending, extra travel time in public transport, car use restriction, total average distance travelled, availability of alternative mobility modes, vehicle performance and availability	France	(Berry et al., 2016)
	Urban sustainable transport composite index	Composite of 3 indicators each for environmental (emissions, energy consumption, land consumption by infrastructure), social (fatalities, density of transport system per passenger, options of vehicles) and economic (cost for government, cost for user, indirect cost/time spent in traffic) dimensions	100 cities	(Haghshenas and Vaziri, 2012)

2 Preparation of mobility data and well-being indicators

2.1 Data on travelled distances

In order to improve cross-country comparability of the data, we pursued the following steps: Unrealistically high or low p-km values for seven countries in the original dataset were replaced, e.g. by drawing on national sources (Ministry of Transport, 2020) or removed, if there was no other source available. For mobility by rail, countries with an average travelled distance below 1 km/cap/yr

(Albania, Zambia, Dem. Republic of Congo) were excluded. For mobility by road, countries with an average travelled distance below 1,100 km/cap/yr (Argentina, Russia) or non-industrialized countries reporting road travel distances above 10,000 km/cap/yr were excluded as these values seemed unrealistic compared to other countries, as well as the mean of 9,504 km/cap/yr, and no other reliable source was available. We used population data from World Bank (2019) to express distances travelled per capita.

2.2 Choice of Rural Access Index used in the analysis

There are two versions of the Rural Access Index, one derived from surveys and one assessed using geospatial analysis. Both express the percentage of households that can reach a road of good or fair quality within 2 km from their home. Road conditions are described as good or fair, if at least a maintainable road with camber and drainage is available. As only very few and rather outdated datapoints are available from surveys, we used the geospatial version of the RAI (Worldbank et al., 2016) for our analysis of recent accessibility assessments at the macro-scale.

3 Estimating material stocks in mobility infrastructure

3.1 OpenStreetMap – Road and rail-based infrastructure

Spatially explicit OpenStreetMap (OSM) data has been shown to be a more than 80% complete representation of societal infrastructures globally, providing substantially better coverage than any other data source at continental to global scales (Barrington-Leigh and Millard-Ball, 2017). The global road length was compared with GRIP4 data (Meijer et al., 2018), a dataset consisting of shapefiles of the global road network based in part on OSM data and in part on regional road network statistics. GRIP4 data is aggregated in major hierarchical road classes similar to those used in this study. The comparison shows that with a total length of nearly 72 million km of roads, the global road network in the OSM dataset is far more extensive than in GRIP4 (21 million km total road length), as illustrated in Figure S 1. Differences can be seen especially for low-class roads such as local and rural roads.

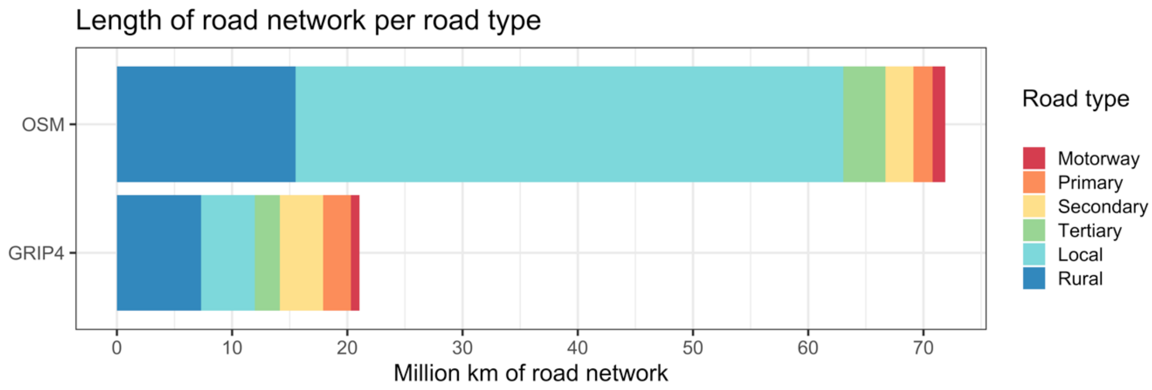

Figure S 1: Comparison of road network length data in OSM and GRIP4. Data source: GRIP4 data (Meijer et al., 2018), OpenStreetMap data (Nov 2021).

Length data for roads and railways (including bridges and tunnels) were obtained from PBF files downloaded via Geofabrik (2021). Features with the key 'highway' and features with the key 'railway' were extracted with PYROSM, an OSM PBF data parser for Python (Tenkanen and pyrosm contributors, 2020). All features of a key were then summarized, thereby providing the total length of each road- or rail-based infrastructure key at country level. Furthermore, keys are denoted as either 'normal', 'bridge', 'tunnel', with the latter two denoting parts of the road or railway network where further civil engineering structures can be found.

In total, the extracted data includes 24 types of roads and nine types of rail-based infrastructure. These were aggregated into six road types (Motorway, Primary, Secondary, Tertiary, Local, Rural) and four rail-based infrastructure types (Railway, Subway, Tram and other rails). A complete list of the OSM keys included and their corresponding aggregation groups (henceforth referred to as stock types) can be found in Table S 2. Some kilometers of road infrastructure are uncategorized, meaning that they do not carry a descriptive OSM key but rather a placeholder. In this study, uncategorized roads were assumed to be local roads.

Table S 2: Classification of roads and rail-based infrastructure and their definitions as given in OSM

Stock type		OSM key	OSM key definition
Roads	Motorway	*motorway*	A restricted access major divided highway, normally with 2 or more running lanes plus emergency hard shoulder. Equivalent to the Freeway, Autobahn, etc.
		motorway_link	The link roads (sliproads/ramps) leading to/from a motorway from/to a motorway or lower-class highway. Normally with the same motorway restrictions.
	Primary	*trunk*	The most important roads in a country's system that aren't motorways. (Need not necessarily be a divided highway.)

		trunk_link	The link roads (sliproads/ramps) leading to/from a trunk road from/to a trunk road or lower-class highway.
	Secondary	*primary*	The next most important roads in a country's system. (Often link larger towns.)
		primary_link	The link roads (sliproads/ramps) leading to/from a primary road from/to a primary road or lower-class highway.
	Tertiary	*secondary*	The next most important roads in a country's system. (Often link towns.)
		secondary_link	The link roads (sliproads/ramps) leading to/from a secondary road from/to a secondary road or lower-class highway.
	Local	*tertiary*	The next most important roads in a country's system. (Often link smaller towns and villages.)
		tertiary_link	The link roads (sliproads/ramps) leading to/from a tertiary road from/to a tertiary road or lower-class highway.
		unclassified	The least important through roads in a country's system – i.e. minor roads of a lower classification than tertiary, but which serve a purpose other than access to properties. (Often link villages and hamlets.)
		residential	Roads which serve as an access to housing, without function of connecting settlements. Often lined with housing.
		living_street	For living streets, which are residential streets where pedestrians have legal priority over cars, speeds are kept very low and where children are allowed to play on the street.
		service	For access roads to, or within an industrial estate, camp site, business park, car park, alleys, etc.
		footway	For designated footpaths; i.e., mainly/exclusively for pedestrians. This includes walking tracks and gravel paths.
		cycleway	For designated cycleways.
		pedestrian	For roads used mainly/exclusively for pedestrians in shopping and some residential areas.
		steps	For flights of steps (stairs) on footways.
	Rural	*track_1*	Roads for mostly agricultural or forestry uses. Solid. Usually a paved or sealed surface.
		track_2	Roads for mostly agricultural or forestry uses. Solid but unpaved. Usually an unpaved track with surface of gravel.
		track_3	Roads for mostly agricultural or forestry uses. Mostly solid. Even mixture of hard and soft materials. Almost always an unpaved track.
		track_4	Roads for mostly agricultural or forestry uses. Mostly soft. Almost always an unpaved track prominently with soil/sand/grass, but with some hard or compacted materials mixed in.
		track_5	Roads for mostly agricultural or forestry uses. Soft. Almost always an unimproved track lacking hard materials, same as surrounding soil.
		track_na	Roads for mostly agricultural or forestry uses. No track type tag present.
Rail-based infrastructure	Railway	*rail*	Full sized passenger or freight trains in the standard gauge for the country or state.
		light_rail	A higher-standard tram system, normally in its own right-of-way. Often it connects towns and thus reaches a considerable length (tens of kilometers).
	Subway	*subway*	A city passenger rail service running mostly grade separated. Often a significant portion of the line or its system/network is underground.
	Tram	*tram*	One or two carriage rail vehicles, usually sharing motor road, sometimes called "street running".
	Other rails	*narrow_gauge*	Narrow-gauge passenger or freight trains. Narrow gauge railways can have mainline railway service like the Rhaetian Railway in Switzerland or can be a small light industrial railway.
		funicular	Cable driven inclined railways on a steep slope, with a pair of cars connected by one cable.
		monorail	A railway with only a single rail. A monorail can run above the rail like in Las Vegas and Disneyland or can suspend below the rail like the Wuppertal Schwebebahn (Germany).
		rack	A cog railway, rack-and-pinion railway or rack railway. This type of railway has a toothed rack rail, usually between the running rails These are common in alpine regions of European countries, including Austria and Switzerland.
		miniature	Miniature railways are narrower than narrow gauge and carry passengers, frequently at an exact scale of "standard-sized" rail (for example "1/4 scale"). They can often be found in parks.

3.2 Spatial coverage and completeness of the OSM data

The extracted OSM data includes the lengths of roads and rail-based infrastructure in 172 countries. In general, data is available at country level, however, since geofabrik.de offers data for some countries only grouped and not individually, data for some countries could only be downloaded grouped into regions. This applies to the Dominican Republic, Haiti and Dominica; Gambia and Senegal; Bahrain, Kuwait, Qatar, Saudi Arabia and the United Arab Emirates (as the Gulf Cooperation Council); and Morocco and Western Sahara. A classification of rail-based infrastructure types was not available for some continental Central American countries, namely Costa Rica, El Salvador, Honduras, and Panama. In these cases, all unclassified rail-based infrastructure was assumed to be railway.

3.3 Material intensity factors for roads

Material intensity (MI) factors for roads are based on layer thicknesses reported for various road types in road design manuals and life cycle assessment studies of road infrastructure for various countries. In order to harmonize the data, only those sources were used that provided specifications on road types equal or analogous to the hierarchy used in the OSM road classification. Consequently, studies only specifying layer thicknesses for roads differentiated by pavement type (e.g. Miatto et al., 2017), traffic levels or other metrics could not be considered. Additionally, the majority of LCA-type studies on road infrastructure lacks proper documentation and supplementary data, making them irreproducible and therefore useless for our purposes (Hoxha et al., 2021). In total, 12 viable sources were gathered, covering various world regions. Layer thicknesses were multiplied with material density factors and averaged to derive a single MI factor (mass per square meter of road) per material and road type.

As can be seen in Figure S 2, two types of pavement layers are distinguished: surface layers (surface and binder course) and base layers (base and subbase course). Usually, aggregate is the main component of base layers while the surface is made up of either asphalt, concrete, or a combination thereof (in so-called composite roads). Since road pavements are most commonly asphalted, design manuals and studies tend to exclusively specify the layer thicknesses of such roads. In the case of the United States, however, a preceding study (Frantz et al., in prep.) went into more detail at a national scale and weighted MI factors for roads according to the shares of each pavement type in the total road network of the United States. Since such information are not available for the majority of countries, this was not deemed a viable option at a global scale. The average global MI factors used in this study are therefore based on asphalted roads which the exception of weighted US MI factors. The subgrade is understood as compacted local earth and not included in the definition of socio-economic material stocks.

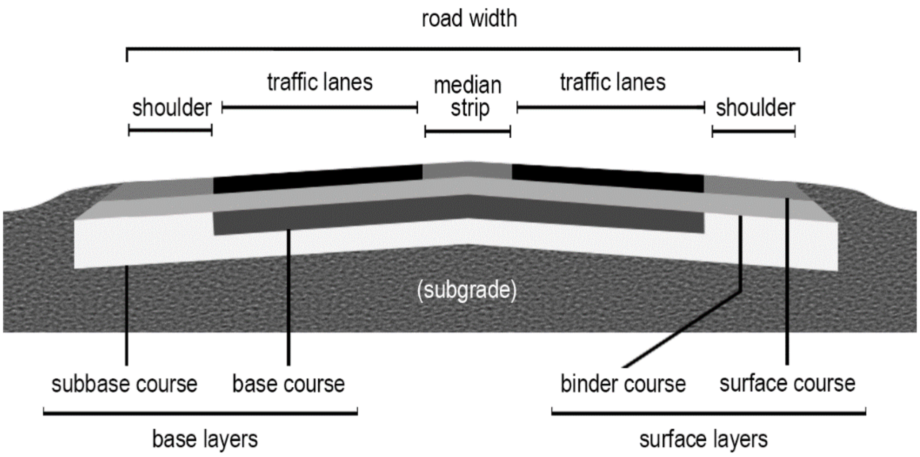

Figure S 2: Road cross section elements as defined in this study and used for calculating material intensities (own illustration)

In a similar manner as for MI factors, road widths were derived as averages of road widths per road type reported in the sources. In this study, we define road width as the sum of the widths of driving lanes, shoulders, and, if applicable, the median strip (see Figure S 2). Additional assumptions were made for local and rural roads. Because spatially explicit information on the actual surface type of roads is lacking, MI factors for local and rural roads had to be weighted in order to account for differences in construction types. Therefore, it was assumed that 50% of local roads are paved and that the other 50% are unpaved. As the sources used for local roads only describe paved local roads, specifications on gravel roads – defined as being constructed without asphalt or concrete pavements

– were used for the MI of unpaved local roads. Furthermore, it was assumed that 75% of unpaved local roads are in fact dirt roads since low-grade roads are commonly more abundant than high-grade roads. Dirt roads were defined as compacted local earth lacking any sort of constructed surface, thus having an MI of zero.

Secondly, rural roads – made up of the five numbered OSM keys for 'tracks' plus unclassified 'tracks_na' – may also be paved, gravel or dirt roads. Only the first track key (track_1) explicitly refers to paved rural roads. The other four track keys are used to classify either gavel or dirt roads. In some regions, the majority of tracks are unclassified and tagged as 'track_na', denoting that the track surface type is unknown. For paved rural roads, the MI factor for paved local roads was used. For the remaining classified track classes (track_2 to track_5), it was assumed that these consist of 50% gravel and 50% dirt roads. The final weighted MI for rural roads of each MI region was then derived from the share of each 'track' class in the total length of the classified track classes.

Whenever bitumen was reported instead of asphalt, bitumen was converted to bitumen based on an assumed 5% share of bitumen in asphalt (Virág et al., 2021). The remaining 95% of asphalt was assumed to aggregate and deducted from the reported amount of aggregate.

3.4 Material intensity factors for rail-based infrastructure

In a similar manner as for roads, we developed material intensity factors for rail-based infrastructure building upon layer thicknesses as reported in design manuals and LCA studies. It was assumed that all railways use international standard track gauge. Furthermore, the weight of sleepers and sleeper plates per meter of rail was calculated by using the average of the reported number of sleepers per km of track.

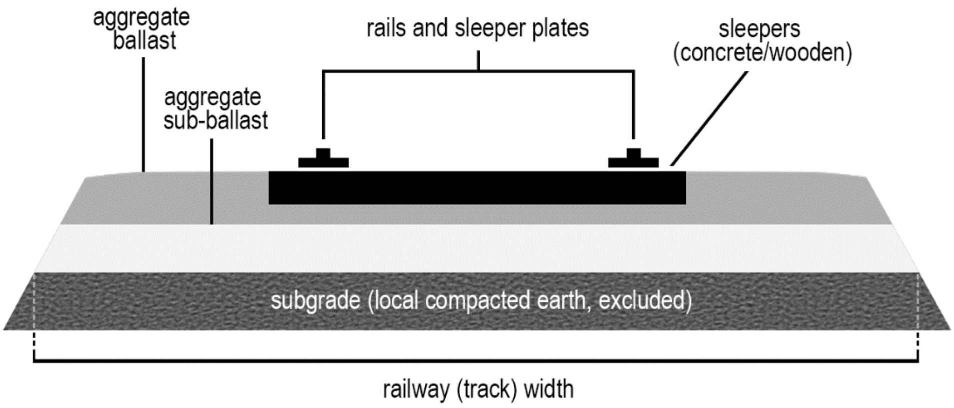

Figure S 3: Railway cross section elements as defined in this study (own illustration)

Figure S 3 shows a typical cross section of the railway track elements considered. The track consists of a steel rail connected via steel plates to wooden or concrete sleepers embedded in an aggregated ballast, below which rests another layer of sub-ballast. As in the case of roads, the subgrade is not considered in this study. Since country-specific ratios of wooden to concrete sleepers were used for the United States and the People's Republic of China, these values were not included in the production of global average railway MI factors.

4 Additional Results

4.1 Correlations of well-being indicators used

Figure S 4 shows a cross-correlation matrix of all well-being indicators used for the empirical analyses.

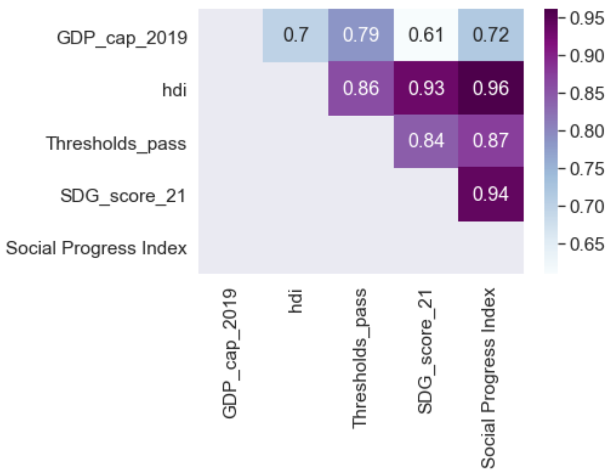

Figure S 4:Cross correlation matrix of well-being indicators used

4.2 Alternative regression models

Detailed regression results for all figures provided as well as additional results for alternative regression models are presented in Table S 3.

Table S 3: Results of regression analysis presented in comparison with results for alternative regression models

Index	Fig. Nr.	Analysis title	n	Linear regression y=a+b*x					Logarithmic (level-log) regression y=a+b*log(x)					Log-level regression log(y) = a + b*x					Log-log regression log(y) = a+ b*log(x)				
				R^2	p-value (x)	Breuschpagan-test	constant	slope (b)	R^2	p-value (x)	Breuschpagan-test	constant	slope (b)	R^2	p-value (x)	Breuschpagan-test	constant	slope (b)	R^2	p-value (x)	Breuschpagan-test	constant	slope (b)
0	2A	Mobility (km/cap/yr) and GDP (US$/cap)	38	0.48	0.000	0.00	-10,078.93	4.17	0.44	0.000	0.26	-295,357.31	35,932.40	0.62	0.000	0.00	8.51	0.00	0.69	0.000	0.41	-3.19	1.45
1	2B	Mobility (km/cap/yr) and HDI	38	0.54	0.000	0.02	0.78	0.00	0.64	0.000	0.74	0.04	0.09	0.55	0.000	0.04	-0.25	0.00	0.66	0.000	0.60	-1.12	0.11
2	2C	Mobility (km/cap/yr) and SDGs reached	38	0.19	0.007	0.05	74.00	0.00	0.30	0.000	0.21	34.50	4.79	0.19	0.006	0.09	4.30	0.00	0.31	0.000	0.29	3.79	0.06
3	2D	Mobility (km/cap/yr) and social thresholds passed	36	0.34	0.000	0.18	3.78	0.00	0.46	0.000	0.28	-24.83	3.51	0.39	0.000	0.87	1.28	0.00	0.56	0.000	0.65	-4.00	0.65
4	2E	Mobility (km/cap/yr) and SPI	38	0.48	0.000	0.26	72.51	0.00	0.64	0.000	0.09	-23.50	11.76	0.47	0.000	0.54	4.28	0.00	0.65	0.000	0.02	3.07	0.15
5	3A	Mobility infrastructure (t/cap) and GDP (US$/cap)	162	0.24	0.000	0.75	3,944.39	179.38	0.21	0.000	0.78	-33,617.65	12,976.41	0.35	0.000	0.27	7.85	0.01	0.46	0.000	0.10	4.43	1.12
6	3B	Mobility infrastructure (t/cap) and HDI	158	0.33	0.000	0.12	0.62	0.00	0.48	0.000	0.02	0.25	0.12	0.30	0.000	0.74	-0.49	0.00	0.44	0.000	0.00	-1.04	0.18
7	3C	Mobility infrastructure (t/cap) and SDGs reached	151	0.29	0.000	0.05	61.28	0.09	0.42	0.000	0.16	37.18	7.82	0.26	0.000	0.53	4.10	0.00	0.38	0.000	0.08	3.74	0.12
8	3D	Mobility infrastructure (t/cap) and social thresholds passed	119	0.43	0.000	0.02	2.08	0.03	0.50	0.000	0.06	-5.14	2.46	0.38	0.000	0.48	0.58	0.01	0.51	0.000	0.27	-1.47	0.69
9	3E	Mobility infrastructure (t/cap) and SPI	151	0.36	0.000	0.04	58.56	0.14	0.47	0.000	0.13	22.06	11.98	0.31	0.000	0.61	4.05	0.00	0.42	0.000	0.04	3.50	0.18
10	S5A	Mobility infrastructure (t/cap) and GDP (US$/cap) - red. sample	38	0.16	0.014	0.71	14,822.73	163.30	0.15	0.015	0.49	-57,617.66	19,734.99	0.19	0.006	0.07	9.45	0.01	0.20	0.005	0.07	6.73	0.73
11	S5B	Mobility infrastructure (t/cap) and HDI - red. sample	38	0.20	0.005	0.00	0.83	0.00	0.20	0.004	0.00	0.65	0.05	0.20	0.005	0.00	-0.19	0.00	0.21	0.004	0.00	-0.40	0.06
12	S5C	Mobility infrastructure (t/cap) and SDGs reached - red. sample	38	0.13	0.028	0.67	75.60	0.02	0.14	0.020	0.95	64.27	3.04	0.12	0.030	0.59	4.32	0.00	0.14	0.022	0.85	4.18	0.04
13	S5D	Mobility infrastructure (t/cap) and social thresholds passed - red. sample	36	0.06	0.152	0.25	6.26	0.01	0.08	0.088	0.19	0.98	1.38	0.07	0.114	0.19	1.72	0.00	0.10	0.058	0.14	0.75	0.25
14	S5E	Mobility infrastructure (t/cap) and SPI - red. sample	38	0.22	0.003	0.00	78.25	0.05	0.26	0.001	0.00	52.14	6.93	0.21	0.004	0.00	4.35	0.00	0.27	0.001	0.00	4.02	0.09
15	4A	RAI and GDP (US$/cap)	152	0.28	0.000	0.00	-20,412.27	501.18	0.21	0.000	0.01	-88,648.55	24,657.73	0.40	0.000	0.84	5.75	0.04	0.33	0.000	0.53	-0.38	2.16
16	4B	RAI and HDI	155	0.47	0.000	0.04	0.37	0.00	0.41	0.000	0.01	-0.38	0.26	0.45	0.000	0.00	-0.87	0.01	0.40	0.000	0.00	-2.00	0.39
17	4C	RAI and SDGs reached	151	0.52	0.000	0.13	42.34	0.36	0.48	0.000	0.16	-12.85	19.15	0.51	0.000	0.01	3.80	0.01	0.48	0.000	0.03	2.92	0.30
18	4D	RAI and social thresholds passed	118	0.40	0.000	0.15	-2.36	0.09	0.33	0.000	0.22	-17.07	5.08	0.41	0.000	0.01	-0.69	0.03	0.35	0.000	0.03	-4.90	1.44
19	4E	RAI and SPI	151	0.55	0.000	0.38	31.92	0.52	0.50	0.000	0.19	-47.48	27.69	0.54	0.000	0.02	3.62	0.01	0.51	0.000	0.01	2.33	0.45
20	S6	Road infrastructure (t/cap) and RAI	158	0.10	0.000	0.75	62.06	0.11	0.13	0.000	0.29	34.69	9.03	0.08	0.000	0.36	4.06	0.00	0.10	0.000	0.13	3.63	0.14
21	-	Road infrastructure (t) and RAI	158	0.03	0.039	0.21	67.67	0.00	0.05	0.006	0.01	9.69	2.96	0.03	0.045	0.33	4.15	0.00	0.04	0.010	0.06	3.17	0.05
22	1D	Mobility infrastructure (t/cap) and distances travelled (km/cap/yr)	38	0.28	0.001	0.64	6,352.46	36.02	0.32	0.000	0.63	-11,453.59	4,741.77	0.27	0.001	0.15	8.70	0.00	0.34	0.000	0.09	6.64	0.54
23	-	Mobility infrastructure (t) and distances travelled (p-km/yr)	38	0.99	0.000	0.70	-43,768.23	0.00	0.39	0.000	0.00	-12,606,402.62	624,857.67	0.38	0.000	0.55	11.22	0.00	0.93	0.000	0.67	-11.87	1.12

As the SPI is a very broad indicator including many different aspects, we tested for differences in the regression results presented in the main text, if individual modules of the SPI were used instead of the compound indicator. Results for all analyses conducted can be found in Table S 4.

Table S 4: Results of regression analysis of travelled distances, mobility infrastructure, rural access (RAI) and social progress, using the three main modules of SPI separately

Analysis title	n	Linear regression y=a+b*x					Logarithmic (level-log) regression y=a+b*log(x)				
		R^2	p-value (x)	Breusch pagan-test	constant	slope (b)	R^2	p-value (x)	Breusch pagan-test	constant	slope (b)
Mobility (km/cap/yr) and SPI - basic needs	38	0.29	0.000	0.12	87.96	0.00	0.50	0.000	0.28	50.58	4.51
Mobility (km/cap/yr) and SPI - well-being	38	0.46	0.000	0.09	72.12	0.00	0.60	0.000	0.24	-27.32	12.22
Mobility (km/cap/yr) and SPI - opportunity	38	0.51	0.000	0.73	57.42	0.00	0.67	0.000	0.00	-93.79	18.56
Mobility (km/cap/yr) and SPI - total	**38**	**0.48**	**0.000**	**0.26**	**72.51**	**0.00**	**0.64**	**0.000**	**0.09**	**-23.50**	**11.76**
Mobility infrastructure (t/cap) and SPI - basic needs	151	0.24	0.000	0.79	68.09	0.12	0.36	0.000	0.00	33.51	11.19
Mobility infrastructure (t/cap) and SPI - well-being	151	0.36	0.000	0.06	58.81	0.14	0.47	0.000	0.15	21.69	12.19
Mobility infrastructure (t/cap) and SPI - opportunity	151	0.40	0.000	0.00	48.78	0.15	0.47	0.000	0.55	10.98	12.58
Mobility infrastructure (t/cap) and SPI - total	**151**	**0.36**	**0.000**	**0.04**	**58.56**	**0.14**	**0.47**	**0.000**	**0.13**	**22.06**	**11.98**
Mobility infrastructure (t/cap) and SPI - basic needs - red. sample	38	0.12	0.035	0.00	90.03	0.02	0.14	0.023	0.00	81.89	2.17
Mobility infrastructure (t/cap) and SPI - well-being - red. sample	38	0.20	0.004	0.00	78.32	0.05	0.24	0.002	0.00	51.51	7.15
Mobility infrastructure (t/cap) and SPI - opportunity - red. sample	38	0.24	0.002	0.01	66.40	0.08	0.30	0.000	0.00	22.99	11.47
Mobility infrastructure (t/cap) and SPI - total - red. sample	**38**	**0.22**	**0.003**	**0.00**	**78.25**	**0.05**	**0.26**	**0.001**	**0.00**	**52.14**	**6.93**
RAI and SPI - basic needs	151	0.50	0.000	0.00	39.79	0.53	0.46	0.000	0.00	-42.07	28.41
RAI and SPI - well-being	151	0.53	0.000	0.46	32.37	0.52	0.47	0.000	0.30	-46.51	27.55
RAI and SPI - opportunity	151	0.49	0.000	0.35	23.59	0.52	0.43	0.000	0.69	-53.87	27.11
RAI and SPI - total	**151**	**0.55**	**0.000**	**0.38**	**31.92**	**0.52**	**0.50**	**0.000**	**0.19**	**-47.48**	**27.69**

In some analyses, outliers were identified. The USA is characterized by far above average mobility levels (p-km) per capita (see Figure 2) and Iceland is the country with the highest mobility infrastructure stock per capita (see Figure 3). Therefore, we present results omitting these outliers. The regression results of travelled distances, GDP and well-being excluding the USA from the sample are shown in Table S 5. The regression results of mobility infrastructure, GDP and well-being excluding Iceland from the sample are shown in Table S 6.

Table S 5: Results of regression analysis of travelled distances, economic activity and well-being presented in Figure 2, using the dataset without the USA for comparison

Analysis title	n	Logarithmic (level-log) regression y=a+b*log(x)					Log-log regression log(y) = a+ b*log(x)				
		R^2	p-value (x)	Breusch-pagan-test	constant	slope (b)	R^2	p-value (x)	Breusch-pagan-test	constant	slope (b)
(A) Mobility (km/cap/yr) and GDP (US$/cap)	37	0.42	0.000	0.18	300,467.14	36,502.29	0.69	0.000	0.61	-3.75	1.52
(B) Mobility (km/cap/yr) and HDI	37	0.66	0.000	0.26	-0.02	0.10	0.67	0.000	0.18	-1.19	0.11
(C) Mobility (km/cap/yr) and SDGs reached	37	0.39	0.000	0.62	26.06	5.73	0.39	0.000	0.74	3.68	0.07
(D) Mobility (km/cap/yr) and social thresholds passed	35	0.47	0.000	0.27	-27.08	3.76	0.58	0.000	0.59	-4.44	0.69
(E) Mobility (km/cap/yr) and SPI	37	0.70	0.000	0.00	-34.96	13.04	0.71	0.000	0.00	2.92	0.16

Table S 6: Results of regression analysis of mobility infrastructure, economic activity and well-being presented in Figure 3, using the dataset without Iceland for comparison

Analysis title	n	Logarithmic (level-log) regression y=a+b*log(x)					Log-log regression log(y) = a+ b*log(x)				
		R^2	p-value (x)	Breusch pagan-test	constant	slope (b)	R^2	p-value (x)	Breuschpagan-test	constant	slope (b)
(A) Mobility infrastructure (t/cap) and GDP (US$/cap)	161	0.20	0.000	0.77	-32,083.80	12,539.84	0.45	0.000	0.12	4.41	1.13
(B) Mobility infrastructure (t/cap) and HDI	157	0.47	0.000	0.02	0.24	0.12	0.43	0.000	0.00	-1.05	0.18
(C) Mobility infrastructure (t/cap) and SDGs reached	150	0.42	0.000	0.15	36.63	7.98	0.38	0.000	0.07	3.73	0.12
(D) Mobility infrastructure (t/cap) and social thresholds passed	119	0.50	0.000	0.06	-5.14	2.46	0.51	0.000	0.27	-1.47	0.69
(E) Mobility infrastructure (t/cap) and SPI	150	0.46	0.000	0.15	21.72	12.08	0.41	0.000	0.05	3.49	0.18

In order to compare the relationship of mobility infrastructure and desired outcomes with the relationship between travelled distances and desired outcomes, the analysis is presented also for the same reduced data sample, that is only including countries, for which total travelled distances per year are known.

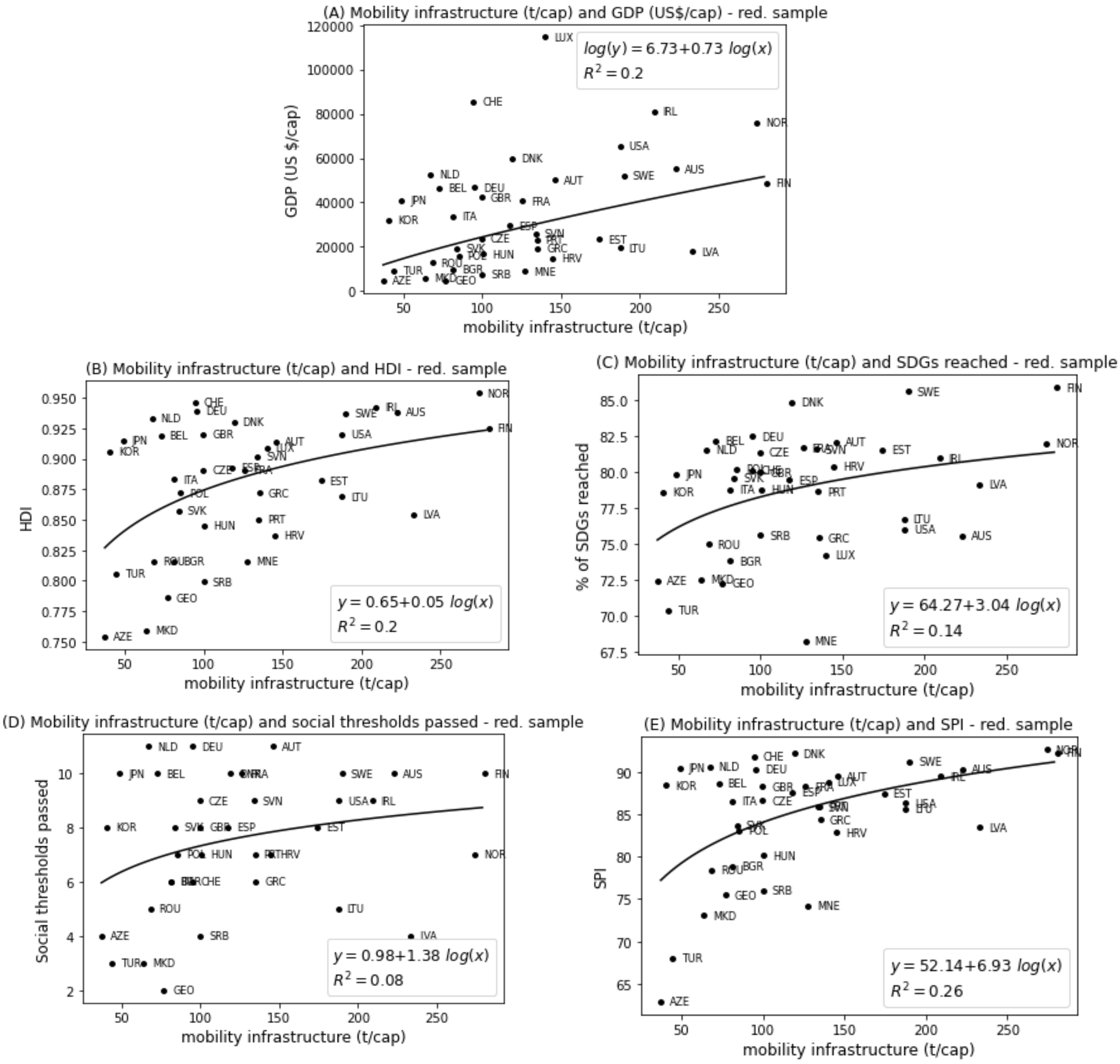

Figure S 5: Regression results of mobility infrastructure stocks/capita, economic activity and well-being indicators for a reduced country sample. a) GDP (log-log), b) Human Development Index (HDI) 2020 (UNDP, 2020) (level-log), c) achievement of Sustainable Development Goals (SDGs) in 2021 (Sachs et al., 2021) (level-log), d) social thresholds reached (O'Neill et al., 2018) (level-log), e) Social Progress Indicator (SPI) 2021 (The Social Progress Imperative, 2021) (level-log). Only those countries were included, for which also data on travelled distances are available.

4.3 Relationship of RAI and road infrastructure stock

The relationship of rural accessibility of road infrastructure (measured by the Rural Access Index, RAI) and road stock levels per capita is basically non-existent. From the shape of the scatterplot, however, it can be seen that a broad range of levels of rural accessibility (up to 80%) are achieved by countries with below ~150 t/cap of road stock. Higher road stock levels achieve only small improvements in rural accessibility, with only few exceptions.

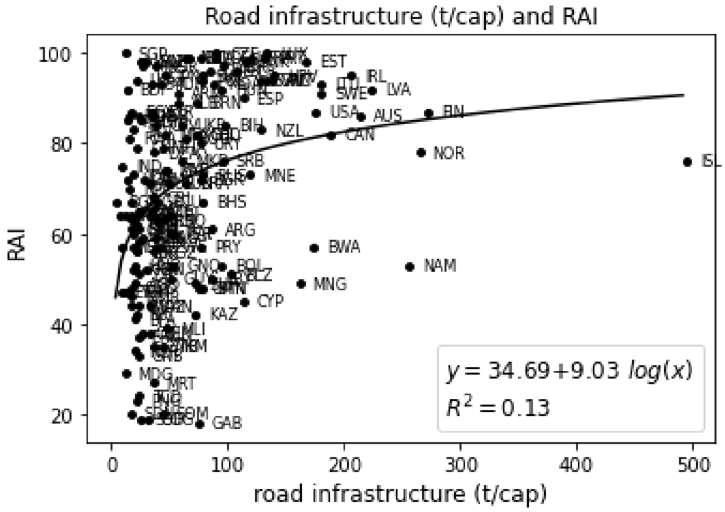

Figure S 6: Logarithmic regression (level-log) of road stocks per capita and Rural Access

4.4 Mobility infrastructure levels at high well-being thresholds

Mobility infrastructure levels associated with reaching high well-being thresholds for the different indicators were calculated by solving the regression equations displayed in Figure 3 for x (infrastructure levels) at different well-being levels (y). For example, with an HDI score of 0.8 (very high development, UNDP (2020)) 92 t/cap of mobility infrastructure are associated (see equation in Figure 3B; 0.8 = 0.25 + 0.12 * log(92)). In total, 34% of all countries analysed reach or surpass the HDI-level of 0.8, almost half of them (16%) do so with less than 92 t/cap of mobility infrastructure. The lowest infrastructure level of a country passing this well-being threshold lies at 15 t/cap (Singapore). Reaching 75% of SDGs is associated with 126 t/cap. 25% of countries in the sample surpass this SDG-threshold, the majority of them (13%) do so with less than 126 t/cap of mobility infrastructure. The lowest stock level in this group is observed in Malta with 29 t/cap. Surpassing 8 of the 11 proposed social thresholds is possible with 207 t/cap, which only 13% of countries achieve. Japan is the country with the lowest mobility infrastructure level (49 t/cap) reaching more than 8 thresholds. Belonging to the two country groups with highest social progress (Tier 1 or 2, The Social Progress Imperative (2021), SPI>80.15) requires 127 t/cap of mobility infrastructure. While 27% of countries analysed surpass this SPI threshold, more than half of them (15%) do so with less than 127 t/cap of mobility infrastructure.

The lowest infrastructure level within the group of countries reaching an SPI of 80.15 or higher lies at 15 t/cap in Singapore.

5 List of country abbreviations

Table S 7: List of country names and corresponding ISO3 codes

ISO3_code	Country Name
AFG	Afghanistan
ALB	Albania
DZA	Algeria
ASM	American Samoa
AND	Andorra
AGO	Angola
ATG	Antigua and Barbuda
ARG	Argentina
ARM	Armenia
ABW	Aruba
AUS	Australia
AUT	Austria
AZE	Azerbaijan
BHS	Bahamas, The
BGD	Bangladesh
BRB	Barbados
BLR	Belarus
BEL	Belgium
BLZ	Belize
BEN	Benin
BMU	Bermuda
BTN	Bhutan
BOL	Bolivia
BIH	Bosnia and Herzegovina
BWA	Botswana
BRA	Brazil
VGB	British Virgin Islands
BRN	Brunei Darussalam
BGR	Bulgaria
BFA	Burkina Faso
BDI	Burundi
CPV	Cabo Verde
KHM	Cambodia
CMR	Cameroon
CAN	Canada

CYM	Cayman Islands
CAF	Central African Republic
TCD	Chad
CHI	Channel Islands
CHL	Chile
CHN	China
COL	Colombia
COM	Comoros
COD	Congo, Dem. Rep.
COG	Congo, Rep.
CRI	Costa Rica
CIV	Cote d'Ivoire
HRV	Croatia
CUB	Cuba
CUW	Curacao
CYP	Cyprus
CZE	Czech Republic
DNK	Denmark
DJI	Djibouti
DMA	Dominica
DOM	Dominican Republic
ECU	Ecuador
EGY	Egypt, Arab Rep.
SLV	El Salvador
GNQ	Equatorial Guinea
EST	Estonia
SWZ	Eswatini
ETH	Ethiopia
FRO	Faroe Islands
FJI	Fiji
FIN	Finland
FRA	France
PYF	French Polynesia
GAB	Gabon
GMB	Gambia, The
GEO	Georgia
DEU	Germany
GHA	Ghana
GIB	Gibraltar
GRC	Greece
GRL	Greenland
GRD	Grenada
GUM	Guam
GTM	Guatemala

GIN	Guinea
GNB	Guinea-Bissau
GUY	Guyana
HTI	Haiti
HND	Honduras
HKG	Hong Kong SAR, China
HUN	Hungary
ISL	Iceland
IND	India
IDN	Indonesia
IRN	Iran, Islamic Rep.
IRQ	Iraq
IRL	Ireland
IMN	Isle of Man
ISR	Israel
ITA	Italy
JAM	Jamaica
JPN	Japan
JOR	Jordan
KAZ	Kazakhstan
KEN	Kenya
KIR	Kiribati
PRK	Korea, Dem. People's Rep.
KOR	Korea, Rep.
XKX	Kosovo
KGZ	Kyrgyz Republic
LAO	Lao PDR
LVA	Latvia
LBN	Lebanon
LSO	Lesotho
LBR	Liberia
LBY	Libya
LIE	Liechtenstein
LTU	Lithuania
LUX	Luxembourg
MAC	Macao SAR, China
MDG	Madagascar
MWI	Malawi
MYS	Malaysia
MDV	Maldives
MLI	Mali
MLT	Malta
MHL	Marshall Islands
MRT	Mauritania

MUS	Mauritius
MEX	Mexico
FSM	Micronesia, Fed. Sts.
MDA	Moldova
MCO	Monaco
MNG	Mongolia
MNE	Montenegro
MOZ	Mozambique
MMR	Myanmar
NAM	Namibia
NRU	Nauru
NPL	Nepal
NLD	Netherlands
NCL	New Caledonia
NZL	New Zealand
NIC	Nicaragua
NER	Niger
NGA	Nigeria
MKD	North Macedonia
MNP	Northern Mariana Islands
NOR	Norway
OMN	Oman
PAK	Pakistan
PLW	Palau
PAN	Panama
PNG	Papua New Guinea
PRY	Paraguay
PER	Peru
PHL	Philippines
POL	Poland
PRT	Portugal
PRI	Puerto Rico
ROU	Romania
RUS	Russian Federation
RWA	Rwanda
WSM	Samoa
SMR	San Marino
STP	Sao Tome and Principe
SEN	Senegal
SRB	Serbia
SYC	Seychelles
SLE	Sierra Leone
SGP	Singapore
SXM	Sint Maarten (Dutch part)

SVK	Slovak Republic
SVN	Slovenia
SLB	Solomon Islands
SOM	Somalia
ZAF	South Africa
SSD	South Sudan
ESP	Spain
LKA	Sri Lanka
KNA	St. Kitts and Nevis
LCA	St. Lucia
MAF	St. Martin (French part)
VCT	St. Vincent and the Grenadines
SDN	Sudan
SUR	Suriname
SWE	Sweden
CHE	Switzerland
SYR	Syrian Arab Republic
TJK	Tajikistan
TZA	Tanzania
THA	Thailand
TLS	Timor-Leste
TGO	Togo
TON	Tonga
TTO	Trinidad and Tobago
TUN	Tunisia
TUR	Turkey
TKM	Turkmenistan
TCA	Turks and Caicos Islands
TUV	Tuvalu
UGA	Uganda
UKR	Ukraine
GBR	United Kingdom
USA	United States
URY	Uruguay
UZB	Uzbekistan
VUT	Vanuatu
VEN	Venezuela, RB
VNM	Vietnam
VIR	Virgin Islands (U.S.)
PSE	West Bank and Gaza
YEM	Yemen, Rep.
ZMB	Zambia
ZWE	Zimbabwe
GCC	Gulf Cooperation Council

DHD	Dominican Republic, Haiti and Dominica
GAS	Gambia and Senegal
MWS	Morocco and Western Sahara
ERI	Eritrea
REU	Réunion
GLP	Guadeloupe
MTQ	Martinique
SHN	Saint Helena
TWN	Taiwan

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