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Measuring "Reasonably Reliable" access to electricity services

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ABSTRACT

While the electricity access rate is regularly measured in most countries, there are no routinely tracked metrics that measure reliability. This paper presents a new approach that: (1) aggregates all available country data on reliability; (2) defines a minimum threshold metric for 'reasonable reliability'; and (3) estimates the number of people without 'reasonably reliable' electricity services. We estimate the number of people without access to reliable electricity is approximately 3.5 billion. This new metric provides a more granular view of the enormous energy access gap globally, and insights for future investment and policy decisions.

1. Introduction

Electricity is a key enabler of economic growth and human development. Reliability and system resilience are critical to unlocking electricity's role in development. Despite this, few studies have focused on measuring these reliability aspects, partly due to poor data availability and a lack of definitions for what suffices as 'reliable' (Bie et al., 2017; Gholami et al., 2018, Shayeghi and Younesi, 2019). The United Nations recognizes the importance of access to energy services through its Sustainable Development Goal (SDG) 7, which seeks to provide access to affordable, reliable, and sustainable modern energy for all people on earth (United Nations, 2015). According to the 2019 and 2020 SDG reports, the number of people without access to electricity declined from 1.2 billion in 2010, to 840 million in 2017, and further to 789 million in 2018 (Laura et al., 2019; Laura et al., 2020).

The electrification rate, or "access rate," is the primary metric used to track SDG7, but because it is binary it provides only a quantity value for measuring "modern energy," and is therefore incomplete. In order to better understand quality of service, we explore the design and present results from a new metric that aims to define a minimum threshold for "decent" or "reasonably reliable" electricity service. Increasing efforts to improve supply reliability will not only ensure households have electricity, but also ensure firms have the needed electricity supply for production purposes as discussed by Moyo (2013).

2. Reliable service

The two most commonly used measurements of electricity supply reliability are the System Average Interruption Duration index (SAIDI) and System Average Interruption Frequency Index (SAIFI) (NERC, 2007; Vugrin et al., 2017). While SAIDI captures the *duration* of power outages in a given year, SAIFI measures the *frequency* of power outages over that same time frame (Warren, 2002; Reed, 2008). According to Taneja utilities on average report only 15% of the outage durations that customer surveys report (Taneja, 2017). This failure to accurately measure their electricity supply reliability is either because utilities lack the technology to do so, or because of the incentive to underreport true reliability figures (Taneja, 2017). This suggests that using utility reported data, such as SAIDI and SAIFI, underestimates outages, and thus using these for reliability metrics is highly conservative. The World Bank compares the performance of each country's electricity supply and finds a positive relationship between SAIDI and SAIFI (Fig. 1).

SAIDI and SAIFI scores remain high even in countries where the access rate is already high or increasing (see Fig. 2). This demonstrates that there is a dimension of this issue that is not being captured by access rate alone, and that there would be additionality to a metric based on SAIDI/SAIFI (Tables 1 and 2).

Previous efforts have been made to move beyond binary measurements of energy access. One such effort, the World Bank's Multi-Tier Framework (MTF) uses a five-tier system to classify energy access based on thresholds or cut-offs (Bhatia and Angelou, 2015).

The reliability framework of the MTF captures the number of disruptions as well as annual SAIDI and SAIFI figures in the analysis. However, the MTF still falls short for several reasons. First, there is no reliability threshold set for lower (0, 1) or middle tiers (2, 3), leaving no way to measure lower-end progress (Fig. 3). Second, reliability thresholds for the upper tiers (4, 5) are set with maximums for frequency and duration far too high to possibly be characterized as a

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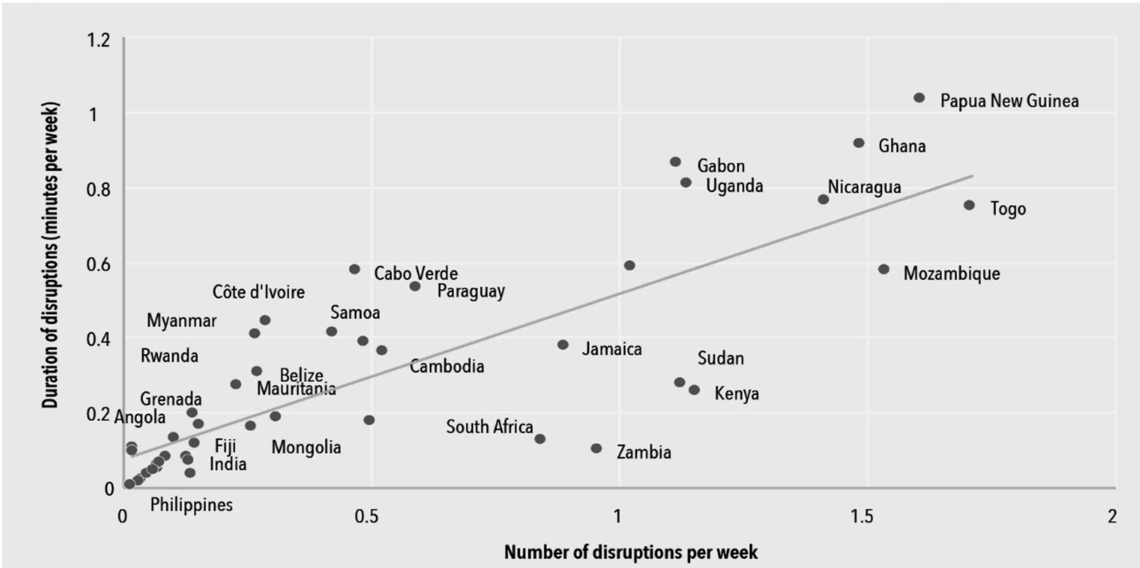


Fig. 1. Scatterplot of Weekly Number and Duration of Disruptions in 2017 (Laura et al., 2019).

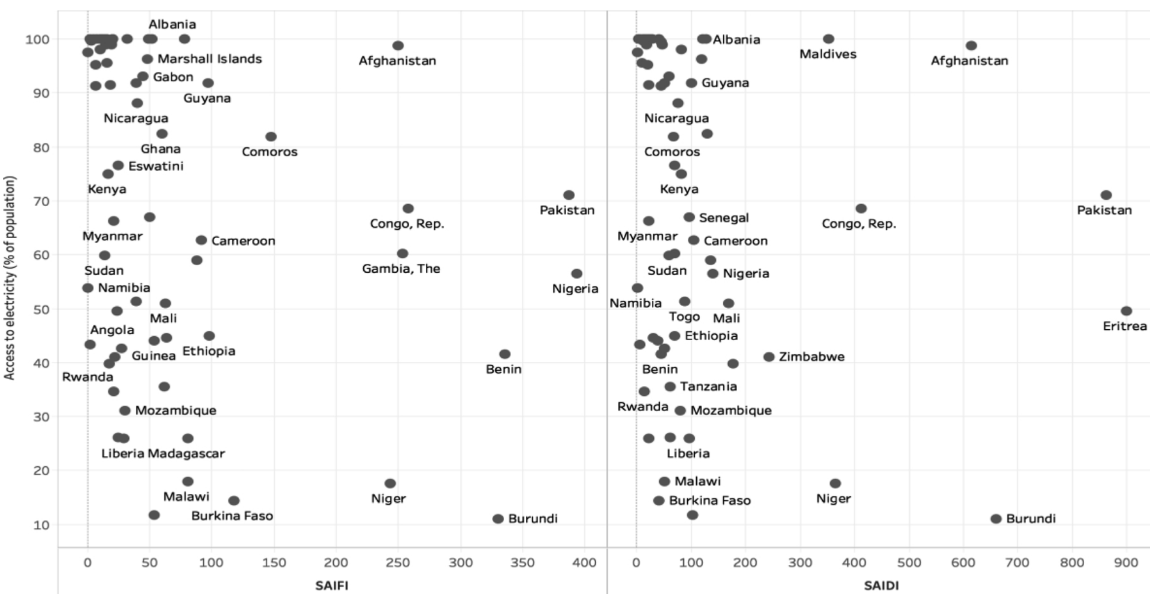


Fig. 2. Plot of Electricity Access Rate and SAIDI/SAIFI for some selected countries.

Table 1
Descriptive Statistics.

Variable	Sample Size	Min	Mean	Max	Yes	No
Duration	179	0	83.17	2352		
Frequency	179	0	151.2	1008		
Duration	179				103	76
Frequency	179				109	70

reliable electricity service. Tier 4 sets a maximum of 14 disruptions per week or a SAIFI index of less than 730 disruptions annually, while Tier 5 sets a maximum of 3 disruptions per week or an annual average disruption rate of up to 156 and a cumulative annual outage duration not exceeding 6,240 minutes or 104 hours (Bhatia and Angelou, 2015). Although this is an improved measure it remains insufficient because of generous thresholds and poor or nonexistent data availability.

The US NERC 2018 technical report utilized several reliability metrics for bulk electricity systems shown in Fig. 4 (North American Electric Reliability Corporation (NERC), 2018)[1] . NERC's metrics are applied to the supply side as opposed to the distribution side of the energy chain, which serves households and firms. Literature on the reliability of electricity in the United States have utilized publicly available SAIDI and SAIFI data from utility companies for their analysis. For instance, Eto et al utilizes yearly SAIDI and SAIFI data to examine trends in electricity reliability in the U.S electric utilities (Eto et al., 2012). For our purposes, the indices that are most proximate to the consumer are preferred (Vugrin et al., 2017; Reed, 2008).

There are also more granular sub-national studies on power quality, such as the study of Unguja, Tanzania by V. Jacome, et. al., (Jacome et al., 2019) The methodologies employed in this study include: (1) open ended interviews; (2) detailed electricity system monitoring; and

[1] NERC -North American Electric Reliability Corporation 2018 technical report uses a variety of metrics to measure the reliability of bulk electricity systems across the United States. These metrics are mainly applied to the supply side of the energy chain.

Table 2
Index, threshold and number of people without reasonably reliable electricity.

Selected index/metric	Benchmark level in a year	Total population without access to reliable electricity services
Frequency	12 outages	1,682,285,035
Duration	12 hours	3,447,150,067
Duration + Frequency	12 hours & outages	3,498,296,614
Duration + Frequency + No Access	12 hours & outages, access	3,529,893,408

Note: These numbers include all but 31 million of the 789 million people without electricity access reported by the World Bank.

Tiers of Reliability of Electricity Supply

RELIABILITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Number of Disruptions					Max 14 disruptions per week	Max 3 disruptions per week with aggregate disruption duration of <2 hours per week
Annual System Average Interruption Frequency Index (SAIFI) and Annual System Average Interruption Duration Index (SAIDI)[a]					<730	<156
						<6,240 mins

Fig. 3. Tier approach to measuring electricity supply reliability (Bhatia and Angelou, 2015).

(3) household surveys (Jacome et al., 2019). While the study presents an excellent assessment of power quality in Unguja, its approach is cumbersome to undertake when dealing with a large number of countries, which would be necessary to create an internationally useful metric.

3. Methodology

Unlike advanced economies that have reliable year-on-year SAIDI and SAIFI data, the data is more sporadic in emerging and developing economies.

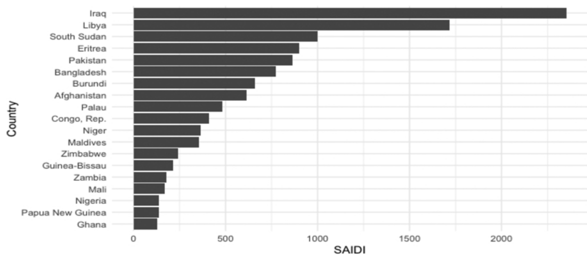
Data for this more global analysis (see Appendix A) is obtained from two sources: (1) available SAIFI and SAIDI data from the World Bank Doing Business Indicators and (2) related data from the Enterprise Survey Database (Anon., 2020a, 2020b). The preferred data is the direct SAIDI and SAIFI data from the Doing Business Indicators, but where it is not available we use survey data on the manufacturing sector from the Enterprise Surveys as a proxy as explained by Cole et al. (Cole et al., 2018) and Mensah (Mensah (2020)). The Enterprise Surveys have monthly data on frequency and duration of power outages for almost all countries, but coverage varies by year, as they are not collected everywhere annually. Although Enterprise Surveys focus on manufacturing firms only, it is still useful due to uniformity in data across countries.

We compare the performance of each country's power supply by setting threshold for duration and frequency measures. We acknowledge that these thresholds are naturally arbitrary to a degree, but nonetheless should better inform developing countries for the purposes of policy and investment. The steps taken for our methodology are as follows:

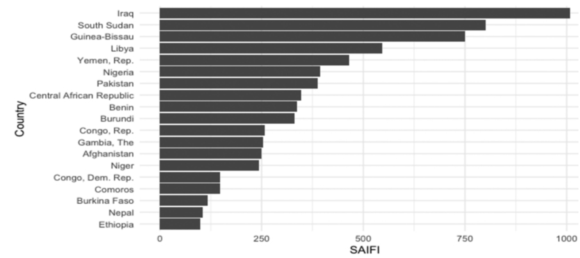
(1) We propose a maximum threshold of 12 outages in a typical year for SAIFI and 12 hours of power outage per year. That is, a maximum frequency of 1 outage per month, and at most 1 hour of outage

RRM	Frequency	Duration	Magnitude	Hours Considered	Calculation Method
LOLH	No	Yes	No	All Hours	Monte Carlo or Convolution
LOLEV	Yes	No	No	All Hours	Monte Carlo or Convolution
LOLE	Yes	Yes	No	Peak Hours or All Hours	Monte Carlo
LOLP	Yes	Yes	No	All Hours	Monte Carlo or Convolution
EUE	Yes	Yes	Yes	All Hours	Monte Carlo or Convolution

Fig. 4. summarizes reliability metrics applied by NERC for the bulk electric system (North American Electric Reliability Corporation (NERC), 2018)[3].



(a) SAIDI bar chart for selected countries



(b) SAIFI bar chart for selected countries

(c) Map of countries with reliable and unreliable electricity service based on SAIDI. "Reliable" they meet the minimum for reliable electricity, "Unreliable" they do not meet the minimum. This is only based on the data for 178 countries

(d) Map of countries with reliable and unreliable electricity service based on SAIFI. "Reliable" they meet the minimum for reliable electricity, "Unreliable" they do not meet the minimum. This is only based on 178 countries.

Fig. 5. a) SAIDI bar chart for selected countries. b) SAIFI bar chart for selected countries. (c) Map of countries with reliable and unreliable electricity service based on SAIDI. "Reliable" they meet the minimum for reliable electricity, "Unreliable" they do not meet the minimum. This is only based on the data for 178 countries. (d) Map of countries with reliable and unreliable electricity service based on SAIFI. "Reliable" they meet the minimum for reliable electricity, "Unreliable" they do not meet the minimum. This is only based on 178 countries.

duration in a typical month.

(2) Applying our proposed maximums in (1) above, we categorize each of the countries either as
(3) "Yes" - Reliable if the index is less than the set threshold (< 12)
(4) "No" - Unreliable if the index is greater than the set threshold (> 12)
(5) We compute the total population of people living in countries that meet either criteria.

We use aggregated data from 179 countries. The average annual duration of outage is approximately 84 hours for all 179 countries, about 4 days in a year. Countries also experience 52 outages in a typical year, exactly one a week, which is well above what could be considered reasonably reliable.

In both instances, the average value well exceeds our proposed 12 hour-12 outage threshold, we find that only 103 countries are below the maximum duration (shaded yellow), while 76 countries (highlighted in red) are not (Fig. 5(c)). Overall, 43% of countries do not meet the threshold for maximum outage duration, while 39% do not meet the threshold for total maximum outages.

4. Results

Based on these results, it is clear that the number of people without access to modern electricity services is far greater than what is concluded based on access rate alone. The total number of people, globally, that do not have reasonable electricity services based on our duration threshold is approximately 3.45 billion, which is several times greater than the 789 million reported based on the access rate. This number inherently includes most of the population without any access, however an additional 31 million is added to this total by people without access in countries that otherwise have reliable electricity according to our standards.

Countries without access to reliable electricity are heavily concentrated in Sub-Saharan Africa (Fig. 5(c) and (d)). Despite energy access efforts, most SSA countries still battle with power outages and such outages tend to last more than 12 hours in a typical year. The electricity situation in the SSA region remains a significant constraint on economic growth, and has been a factor in preventing countries from growing faster or creating sufficient jobs (Andersen and Dalgaard, 2013). Ghana, for example, is a country where the access rate is increasing relatively rapidly, but economic growth is still substantially constrained by expensive and poor quality electricity services (Bazilian and Ayaburi, 2020). Within this group there is substantial variance, Fig. 5(a) & (b) show that some countries are much closer to reasonable reliability than others.

If we double our duration metric and instead utilize an alternative 24 hour threshold it shows about 1.6 billion do not have access to reliable electricity, a substantial drop in large part because India's SAIDI is 18.9. Since it is difficult to reasonably state that the 1.4 billion people of India have uniformly reliable or unreliable access, subnational data could be used to further narrow this analysis. Other large countries such as Nigeria could warrant the same approach (Shubra Das et al., 2019). Using our frequency threshold suggests about 1.7 billion people do not have reliable access, still more than twice the number of people without access alone.

5. Conclusions

As the world moves towards energy access for all, it is important to highlight that the quality of electricity services plays a key role in economic development and poverty alleviation. Governments and organizations have historically focused on ensuring connections to power, but many connected households and firms experience poor or unreliable power supply, which affects their ability to carry out economic activities (Cole et al., 2018; Mensah, 2020; Bazilian and Ayaburi, 2020). Understanding how to measure access to reliable electricity services is necessary to ensure the full achievement of SDG7. Although defining access to quality electricity is subjective, we have proposed thresholds for two meaningful measures as proxies. The proposed thresholds can help augment and refine the way we measure the goals of SDG7, and inform policy approaches.

We find that the number of people without access to electricity, and also to decent quality access, is roughly 3.5 billion globally. Previous research has aimed to develop a better measure for reliability (e.g., Kunaifi and Reinders, 2018), who utilize a perceived SAIDI and SAIFI metric to demonstrate the disparity between what grid users experience and what utilities report.

These data illustrate that instead of focusing primarily on expanding connections, policymakers must aim for a reasonably reliable level of electricity service (Cole et al., 2018. Power system resilience is another important part of energy supply (Molyneaux et al., 2012), although it is beyond this current study.

This paper presented a simple, new electricity reliability method to help determine the number of people without access to decent electricity services. We show the number is approximately 3.5 billion, a number more than three times greater than the 789 million reported in SDG tracking report in 2018.

Declaration of Competing Interest

The authors report no declarations of interest.

Appendix A. [2]

Country	Code	SAIDI	SAIFI	Access Rate	Country	Code	SAIDI	SAIFI	Access Rate
Afghanistan	AFG	615	250.0	98.7	Lebanon*	LBN	48.0	7.2	100
Albania	ALB	87.2	45.9	100	Lesotho*	LSO	79.2	26.4	47
Algeria	DZA	5.2	9.5	100	Liberia	LBR	85.3	24.7	25.9
Angola	AGO	5.2	2.3	43.3	Libya	LBY	1715.5	547.0	67
Antigua and Barbuda	ATG	6.5	10.5	100	Lithuania	LTU	0.5	0.4	100
Argentina	ARG	4.5	16.2	100	Luxembourg	LUX	0.3	0.2	100
Armenia	ARM	3.8	3.3	100	Madagascar*	MDG	22.8	80.4	25.9
Australia	AUS	1.3	0.7	100	Malawi*	MWI	51.6	80.4	18.0
Austria	AUT	0.7	0.7	100	Malaysia	MYS	0.5	0.6	100
Azerbaijan	AZE	1.0	1.7	100	Maldives	MDV	353.1	78.0	100
Bahamas, The	BHS	6.9	8.5	100	Mali	MLI	168.0	62.5	50.9
Bahrain	BHR	0.7	0.4	100	Malta	MLT	2.0	1.9	100
Bangladesh*	BGD	774	14.4	85.2	Marshall Islands	MHL	120.0	48	96.4
Barbados	BRB	5.0	5.7	100	Mauritania*	MRT	31.2	63.6	44.5
Belarus	BLR	0.3	0.3	100	Mauritius	MUS	1.6	0.5	97.5
Belgium	BEL	0.4	0.4	100	Mexico	MEX	0.7	0.9	100
Belize	BLZ	43.7	19.8	99.5	Moldova	MDA	1.2	1.3	100
Benin*	BEN	44.4	336.0	41.5	Mongolia	MNG	81.0	10	98.1
Bhutan	BTN	11.0	6.1	100	Montenegro	MNE	27.1	20.0	100
Bolivia	BOL	6.5	7.3	95.6	Morocco	MAR	0.6	2.3	100
Bosnia and Herzegovina	BIH	2.3	0.6	100	Mozambique*	MOZ	80	30	31.1
Botswana*	BWA	32.4	49.2	64.9	Myanmar	MMR	22	21.3	66.3
Brazil	BRA	12.6	5.9	100	Namibia	NAM	0.8	0.2	53.9
Brunei Darussalam	BRN	0.5	0.4	100	Nepal*	NPL	43.2	104.4	93.9
Bulgaria	BGR	5.0	4.1	100	Netherlands	NLD	0.6	0.3	100
Burkina Faso*	BFA	39.6	117.6	14.4	New Zealand	NZL	2.0	1.1	100
Burundi	BDI	660	330	11.0	Nicaragua	NIC	73.7	39.6	88.1
Cabo Verde	CPV	24.4	30	93.6	Niger	NER	365	243.3	17.6
Cambodia	KHM	22.8	18.7	91.6	Nigeria*	NGA	139.2	393.6	56.5
Cameroon*	CMR	104.4	91.2	62.7	North Macedonia	MKD	5.6	12.5	100
Canada	CAN	0.9	1.3	100	Norway	NOR	0.8	1.1	100
Central African Republic*	CAF	97.2	348	32.4	Oman	OMN	2.8	1.4	100
Chad*	TCD	102	54	11.8	Pakistan*	PAK	861.7	387.2	71.1
Chile	CHL	3.4	1.34	100	Palau	PLW	482.3	28.0	100
China	CHN	1.4	0.3	100	Panama	PAN	0.9	0.9	100
Colombia	COL	6.3	5.8	99.9	Papua New Guinea	PNG	136.0	88	59.0
Comoros*	COM	67.2	147.6	81.9	Paraguay	PRY	41	32.8	100
Congo, Dem. Rep.*	COD	67.2	147.6	19.0	Peru	PER	8.9	2.3	95.2
Congo, Rep.*	COG	412	258	68.5	Philippines	PHL	4.6	4.0	94.9
Costa Rica	CRI	0	0	100	Poland	POL	1.2	1.0	100
Côte d'Ivoire	CIV	15	19	67.0	Portugal	PRT	0.6	0.8	100
Croatia	HRV	5.0	1.7	100	Puerto Rico	PRI	8.0	4.4	100
Cyprus	CYP	0.5	0.2	100	Qatar	QAT	0.4	0.2	100
Czech Republic	CZE	0.5	0.3	100	Romania	ROU	2.6	2.7	100

[2] Countries with data from the Enterprise Survey Database are denoted by an asterisk (*).

[3] The reliability metrics used in the NERC's report: LOLH - Loss of Load Hours "the expected number of hours per time period (often a year) when a system's hourly demand is projected to exceed the generating capacity". LOLEV - Loss of Load Events "the number of events in which the system load is not served in a given time period". LOLE - Loss of Load Expectation "The expected number of days for which the generation capacity is insufficient to serve the demand at least once per day". LOLP - Loss of Load Probability "The probability of system daily peak or hourly demand exceeding the available generating capacity during a given period". EUE - Expected Unserved Energy "Summation of the expected number of megawatt hours of demand that will not be served in a given time period as a result of demand exceeding the available capacity across all hours".

Denmark	DNK	0.5	0.5	100
Djibouti*	DJI	19.2	19.2	60.4
Dominica	DMA	0.8	0.5	100
Dominican Republic	DOM	7.9	11.2	100
Ecuador	ECU	2.1	3.0	100
Egypt, Arab Rep.	EGY	2.7	2.8	100
El Salvador	SLV	14.5	7.5	100
Eritrea*	ERI	900	24	49.6
Estonia	EST	0.9	0.4	100
Eswatini	SWZ	69.0	24.4	76.5
Ethiopia*	ETH	69.6	98.4	45.0
Fiji	FJI	6.9	5	99.6
Finland	FIN	0.0	0.1	100
France	FRA	0.2	0.2	100
Gabon*	GAB	58.2	45	93.0
Gambia, The*	GMB	69.6	253.2	60.3
Georgia	GEO	11.4	7.4	100
Germany	DEU	0.2	0.2	100
Ghana	GHA	129.8	59.8	82.4
Greece	GRC	2.2	1.4	100
Grenada	GRD	5.1	7.0	95.3
Guatemala	GTM	3.6	2.5	94.7
Guinea*	GIN	38.4	54	44
Guinea-Bissau*	GNB	215	748.8	28.7
Guyana	GUY	100	97	91.8
Honduras	HND	50.0	38.9	91.9
Hong Kong, China	HKG	0.4	0.2	100
Hungary	HUN	2.9	1.3	100
Iceland	ISL	0.6	0.7	100
India	IND	18.9	6.4	95.2
Indonesia	IDN	4.5	2.9	98.5
Iran, Islamic Rep.	IRN	5.2	4.8	100
Iraq	IRQ	2352	1008	99.9
Ireland	IRL	0.3	0.2	100
Israel	ISR	1.7	1.9	100
Italy	ITA	0.5	1.5	100
Jamaica	JAM	46.2	19.5	98.9
Japan	JPN	0.1	0.1	100
Jordan	JOR	2.2	1.5	99.9
Kazakhstan	KAZ	0.8	1.0	100
Kenya	KEN	80.9	17.0	75
Korea, Rep.	KOR	0.1	0.1	100
Kosovo	XKX	24.2	11.9	100
Kuwait	KWT	0.1	0.7	100
Lao PDR	LAO	8.7	7.2	97.9
Latvia	LVA	1.1	0.6	100
Russian Federation	RUS	0.3	0.1	100
Rwanda*	RWA	14	21.1	34.7
Samoa	WSM	25.3	20	100
San Marino	SMR	0.3	1.5	100
Saudi Arabia	SAU	1.9	1.2	100
Senegal	SEN	95.4	50.4	67.0
Serbia	SRB	4.0	3.5	100
Seychelles	SYC	0.4	0.1	100
Sierra Leone*	SLE	62.1	24.8	26.1
Singapore	SGP	0	0.0	100
Slovak Republic	SVK	0.8	0.5	100
Slovenia	SVN	0.5	0.2	100
Solomon Islands	SLB	6.6	3.9	66.7
South Africa*	ZAF	44.0	6.5	91.2
South Sudan*	SSD	1000	800	28.2
Spain	ESP	0.7	0.9	100
Sri Lanka	LKA	2.8	2.7	99.6
St. Lucia	LCA	0.4	0.4	99.5
Sudan	SDN	58.6	14.4	59.8
Suriname*	SUR	33.6	33.6	97.4
Sweden	SWE	0.6	0.5	100
Switzerland	CHE	0.2	0.2	100
Taiwan, China	TWN	0.3	0.2	N/A
Tajikistan*	TJK	33.6	15.6	99.3
Tanzania	TZA	60.4	61.9	35.6
Thailand	THA	0.5	1.0	100
Togo*	TGO	89.0	39	51.3
Tonga	TON	18.8	14.7	98.9
Trinidad and Tobago	TTO	6.7	4.7	100
Tunisia	TUN	3.1	2.5	99.8
Turkey	TUR	20.0	11.3	100
Uganda	UGA	50.2	27.8	42.7
Ukraine	UKR	3.9	2.1	100
United Arab Emirates	ARE	0.3	0.3	100
United Kingdom	GBR	0.3	0.2	100
United States	USA	0.9	0.4	100
Uruguay	URY	5.6	3	100
Uzbekistan	UZB	0.2	0.1	100
Vanuatu	VUT	6.0	6.2	61.9
Venezuela, RB*	VEN	25.2	31.2	100
Vietnam	VNM	21.4	10.8	100
West Bank and Gaza	PSE	8.4	12.1	100
Yemen, Rep.*	YEM	54.0	465.6	62
Zambia	ZMB	176.0	17.9	39.8
Zimbabwe	ZWE	243.6	21.7	41.0

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