

WORLD STATE RANKING FOR WIND ENERGY AND PHOTOVOLTAICS

Stephan Volkwein^{1*}, Fabio Veronesi², Stefano Grassi², Roland Schenkel², Ariadni Gaki², Charalampos Gkonos², Athina Korfiati², Martin Raubal², Lorenz Hurni²

¹Renewables-Now Aktiengesellschaft, Switzerland

²Institute of Cartography and Geoinformation, ETH Zurich, Switzerland

* Corresponding author: port@Renewables-Now.ch, Renewables-Now Aktiengesellschaft, In der Ey 17, 8047 Zürich, Switzerland

KEYWORDS

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ABSTRACT

The SolarSuperState Ranking 2011 is the first ranking of all 196 states of the world based on the capacity per population for the two categories wind energy and photovoltaic usage. The reporting date is 31 December 2010. The cumulative installed capacity, the cumulative installed capacity per population, and the world rank are given as figures. Most top ten ranks in both rankings wind and solar are crowded by European states, no one by an African state. At the world level, exceptional states are

Denmark	(world rank 1 in category wind)
Vatican City State	(world rank 1 in category solar)
Germany	(in the top ten lists of both categories wind and solar)
Spain	(in the top ten lists of both categories wind and solar)

In the whole world, there exists only one state cluster for each of the two categories wind and solar with many top ten states. In the center of these two clusters is always Germany.

INTRODUCTION

Renewable energy usage can contribute significantly to the solution of many local, regional and global problems like air, water and soil pollution by fossil and nuclear energies (Scheer, 2012), global warming (Fell, 2012) or the threat of a total global economy collapse caused by Peak Oil (Zentrum fuer Transformation der Bundeswehr, 2010). In particular, solar and wind energy have huge potentials and are capable to substitute nuclear and fossil energies (Volkwein, 2014). The ensemble of solar (especially photovoltaics) and wind energy can be deployed fast and in every state of the world. Some states are more favorable for photovoltaics others more for wind energy. Many states have big potentials for both technologies. There is no state of the world where neither photovoltaics nor wind energy works. The first industrial applications of wind energy for electricity production date back to around 1905 (Denmark: Maegaard and co-workers, 2013) and for photovoltaics to 1956 (United States of America). To the best of our knowledge, a public global compilation of cumulative installed capacity figures of wind power and photovoltaics for all existing states of the world first published 2010 or earlier does not exist. The resulting list is called SolarSuperState Ranking.

METHODOLOGY

Reporting date

The reporting date of each SolarSuperState Ranking is 31 December 2010. For the population data, those statistics are chosen that are closest to the 31 December 2010. Major population data sources are the official national statistics and The World Factbook (Central Intelligence Agency, 2015). The precision of the population statistics is often better than the precision of the cumulative installed capacity statistics of photovoltaics.

State definition

Based on the reporting date 31.12.2010, there existed 196 states (appendix table 2). Among these states are all 193 member states of the United Nations in the year 2014, excluding South Sudan which was formed after the reporting date of 31.12.2010. The remaining four states are Vatican City State, Palestine, Kosovo, and Taiwan.

Definition cumulative installed capacity

The cumulative installed capacity includes off-grid and on-grid systems. Systems that are intended to be on-grid systems must be connected to the grid, else they are not counted as installed capacity.

Categories wind and solar

The SolarSuperState Ranking has two separate rankings: wind and solar. In the category wind, the cumulative installed capacity of wind power per capita is listed. For every category, the appendix table 2 lists the following data:

- (a) State name
- (b) Population size
- (c) Rank of the state at world level
- (d) Cumulative installed capacity per population
- (e) Cumulative installed capacity

The items (c), (d), and (e) are listed separately for the two categories, the other items not.

In the category solar only photovoltaics is counted. Firstly, photovoltaics can substitute directly fossil and nuclear electricity. Secondly, photovoltaics can also substitute thermal energy applications of nuclear and fossil energy directly or indirectly via heat pumps or power to gas. Thirdly, photovoltaics works in cold climates like Sweden and in hot climates like Saudi Arabia. Finally, photovoltaics is the leading solar energy technology by cumulative installed capacity. Therefore, the category solar uses as indicator only photovoltaics and not solar thermal electricity.

Wind power

The primary data source for the cumulative installed capacity of wind power is World Wind Energy Association (2014). For several states, these raw data were aggregated to the state level according to the definition of the state. For Denmark mainland the official data (Energistyrelsen, 2014) have been used. Calculation example for the kingdom of Denmark:

3802 Megawatt Denmark mainland	(Energistyrelsen, 2014)
4 Megawatt Faroe Islands	(World Wind Energy Association, 2014)
0 Megawatt Greenland	(World Wind Energy Association, 2014)
3806 Megawatt Kingdom of Denmark	(total, SolarSuperState Ranking 2011)

In case of the availability of national data by the national government, these data were preferred (example Denmark mainland). In the case of Portugal, the data of APREN (2012) were preferred because of better data quality.

France data include data for Guadeloupe, Reunion, Martinique, and St. Pierre et Miquelon. Netherlands data are with data of Curacao and Bonaire. United Kingdom includes Falkland Islands.

Photovoltaics

Primary data source for photovoltaics is EPIA (2013). These data were complemented by data of EUROBSERV'er (2013), data of national governments, publications in the internet about big photovoltaic projects, unofficial data of the European Union, data from E8 (2009), data obtained by direct contact with dominant national utility companies in some states like Liechtenstein and Tonga, and data of Werner and co-workers (2011, 2013, 2014).

If in newer publications of the same research team or research institution, the data for 2010 are corrected, then the newer data were used (especially in the case of Werner and coworkers (2011, 2013, 2014) and EUROBSERV'er (2013). The data of Werner and co-workers (2011, 2013, 2014) are only used, when data of other sources that cover the total state are not available.

Uncertainty range

All data of cumulative installed capacity below 1 Watt per capita are only specified to be smaller than 1 Watt per capita. No uncertainty range is supplied for such data. All other uncertainty ranges are rough estimates. The higher the figure the lower is the relative uncertainty factor because more research is globally used to determine these relative big figures. The uncertainty factor is estimated to be 1.03 in both directions (lower (UFL) and upper uncertainty factor (UFU)) for cumulative capacities of at least 100 Watt per capita (Table 1). For cumulative capacity figures between 10 and 100 Watt per capita, the uncertainty factors are estimated to be 1.1 in the category wind, and 1.2 in the category solar. Usually, the wind power capacity depends on a fewer number of installations than the photovoltaic capacity. Therefore, the uncertainty factors for the category wind are usually lower than for the category solar.

For states with less than 10 Watt per capita and at least 1 Watt per capita, the uncertainty factors are estimated to be 1.2 (wind) and 2 (solar).

Table 1: Lower uncertainty factors (UFL) and upper uncertainty factors (UFU) for cumulative installed capacity (C)

C Watt / capita	UFL (Wind) 1	UFU (Wind) 1	UFL (Solar) 1	UFU (Solar) 1
< 1				
1 - 10	1.2	1.2	2	2
10 - 100	1.1	1.1	1.2	1.2
> 100	1.03	1.03	1.03	1.03

Ranking

The ranking is based on the capacity per population. The states with less than 1 Watt per capita capacity are simply ranked by increasing population. It is assumed that states with bigger populations have more power and more possibilities to install wind power and photovoltaics. These states get a penalty in the ranking which is linked to the population size. All states with at least 1 Watt per capita are ranked by the cumulative installed capacity per capita. The appendix table lists the state rank in the categories wind and solar.

RESULTS

Many state statistics still ignore the statistics about wind and solar energy because they think that hydro power, atomic and fossil energies are the only ones that could contribute significantly to the energy production and consumption. This is one major reason for the high uncertainty factors of the cumulative installed capacity in many states. The national German wind and photovoltaic policy initiatives in 1990 and 2000 triggered national policy initiatives in neighboring states of Germany and in southern Europe. In 2010, the leading role of the German wind energy and photovoltaic industry is due to German policy initiatives and to a minor portion to know-how from other states (Denmark, US).

CONCLUSIONS AND FURTHER RESEARCH

The top ten groups in both categories contain states with small and with big populations. This signifies that the ranking methodology gives equal opportunities to small and big states to conquer a top position.

Except from Vatican City State, only Germany and the Czech Republic, have possibly more photovoltaic modules than cars and other vehicles with internal combustion engine in the year 2010. One photovoltaic module is much cheaper than a vehicle with internal combustion engine. One important reason might be that these states with little photovoltaics blocked politically the rapid deployment of photovoltaics in their countries in the last decades.

European states dominate the top ten in all categories. Germany due to one of the world first feed-in tariff systems is in the center of state clusters of top ten states with different neighboring states depending on the category. These two clusters are separated from southern European top ten states in one or two categories (Italy (Solar), Spain (Wind and solar), Portugal (Wind)) by less successful states (France (both categories), Switzerland (both categories), and Austria (only in solar)). The two nuclear energy strongholds France and Switzerland showed more political resistance against wind energy and photovoltaics deployment in the first decade of this millennium than several of their neighboring states. Austria has a strong natural gas industry that delayed politically the solar energy deployment compared to its more successful neighbors Germany, Czech Republic and Italy. In the category wind, only two non-European states are in the top ten (USA and Canada), in the category solar only one non-European state joins the top ten (Japan).

The two most populous states of the world - China and India - occupy the two last ranks in the category solar but are much better in the category wind (ranks 27 and 41). Some states already cover the cumulative installed capacity (wind, solar) in their national statistics. We recommend that all states include the cumulative installed capacity of wind power and photovoltaics in their annual national statistics and grant open access to them. Every state implementing suitable national legal frameworks still has the chance to conquer in a few years a top position in the SolarSuperState Ranking.

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APPENDIX

Table 2: SolarSuperState Ranking 2011. Cumulative installed capacity (C) in unit "Watt per capita" (W/c), installed capacity (I) in unit "Megawatt" (MW)

State	Populati- on, 1000	Wind Rank	Wind C, W/c	Wind C, MW	Solar Rank	Solar C, W/c	Solar I, MW	State	Populati- on, 1000	Wind Rank	Wind C, W/c	Wind C, MW	Solar Rank	Solar C, W/c	Solar I, MW
Afghanistan	29121	175	< 1		164	< 1	1.3	Chad	10329	148	< 1		133	< 1	0.54
Albania	2987	107	< 1		89	< 1	0.03	Chile	17248	43	10	172	149	< 1	3.7
Algeria	34586	181	< 1	0.1	170	< 1	7.1	China	1347830	27	33	44733	196	< 1	893
Andorra	85	68	< 1		55	< 1	0.05	Colombia	45925	184	< 1	20	177	< 1	6.9
Angola	13100	152	< 1		139	< 1	2.9	Comoros	798	90	< 1		75	< 1	0.16
Antigua and Barbuda	87	69	< 1		47	1	0.09	Congo (Kinshasa)	71713	188	< 1		181	< 1	0.99
Argentina	41300	57	1	54	174	< 1	11.7	Congo (Brazzaville)	3686	114	< 1		98	< 1	1.7
Armenia	3000	108	< 1		90	< 1	0.07	Costa Rica	4302	30	29	123	102	< 1	1
Australia	22802	20	82	1880	11	22	504	Cote d'Ivoire	20617	164	< 1		152	< 1	
Austria	8415	9	120	1011	19	12	103	Croatia	4291	37	16	70	30	3	11.3
Azerbaijan	8300	139	< 1		123	< 1	0.18	Cuba	11242	58	1	11.7	135	< 1	2.1
Bahamas, The	310	78	< 1		65	< 1	0.21	Cyprus	803	14	102	82	21	7	6
Bahrain	738	89	< 1		74	< 1	0.05	Czech Republic	10562	33	20	215	3	185	1953
Bangladesh	158570	194	< 1		191	< 1	34.7	Denmark	5662	1	663	3752	41	1	7
Barbados	286	77	< 1		64	< 1	0.14	Djibouti	906	91	< 1		35	2	1.4
Belarus	9600	142	< 1	2	126	< 1	2.1	Dominica	72.66	15	99	7.2	53	< 1	0.04
Belgium	10951	22	80	886	5	95	1044	Dominican Republic	9379	141	< 1	0	125	< 1	1.9
Belize	315	79	< 1		66	< 1	0.03	Ecuador	15007	158	< 1	2.5	145	< 1	1.2
Benin	9100	140	< 1		124	< 1	0.55	Egypt	79618	47	7	550	184	< 1	5.5
Bhutan	691	88	< 1		73	< 1	0.02	El Salvador	6277	128	< 1		115	< 1	0.32
Bolivia	9900	145	< 1	0.01	129	< 1	3.1	Equatorial Guinea	676	87	< 1		72	< 1	0.54
Bosnia and Herzegovina	4600	119	< 1		105	< 1	0.13	Eritrea	5824	126	< 1	0.8	112	< 1	0.41
Botswana	2030	101	< 1		38	1	2.7	Estonia	1340	12	111	149	32	2	3
Brazil	195633	53	5	931	193	< 1	26.6	Ethiopia	82102	189	< 1		185	< 1	6.9
Brunei Darussalam	395	82	< 1		68	< 1	0.01	Fiji	849	40	12	10	76	< 1	0.47
Bulgaria	7365	23	51	375	31	2	18	Finland	5392	26	37	197	25	5	26.1
Burkina Faso	16200	160	< 1		147	< 1	1.8	France	65821	18	86	5660	14	16	1025
Burundi	9860	144	< 1		128	< 1	0.19	Gabon	1475	96	< 1		80	< 1	0.17
Cambodia	14500	155	< 1		142	< 1	2.1	Gambia, The	1705	99	< 1		83	< 1	0.69
Cameroon	19300	162	< 1		150	< 1	0.98	Georgia	4636	120	< 1		106	< 1	0.36
Canada	34693	10	116	4009	22	6	200	Germany	80300	4	339	27214	2	219	17554

State	Populati- on, 1000	Wind Rank	Wind C, W/c	Wind C, MW	Solar Rank	Solar C, W/c	Solar I, MW	State	Populati- on, 1000	Wind Rank	Wind C, W/c	Wind C, MW	Solar Rank	Solar C, W/c	Solar I, MW
Cape Verde	509	50	6	2.8	15	15	7.5	Ghana	24233	170	< 1		159	< 1	0.84
Central African Republic	4422	118	< 1		103	< 1	0.15	Greece	11305	13	107	1208	12	18	206
Grenada	110	49	6	0.7	57	< 1	0.1	Luxembourg	511.8	21	82	42	8	58	29.5
Guatemala	13824	154	< 1		141	< 1	1.8	Macedonia	2055	103	< 1		85	< 1	0.38
Guinea	10058	147	< 1		132	< 1	1.2	Madagascar	21926	165	< 1		154	< 1	1.5
Guinea-Bissau	1647	97	< 1		81	< 1	0.47	Malawi	14901	157	< 1		144	< 1	0.37
Guyana	753	35	18	13.5	33	2	1.5	Malaysia	28334	173	< 1		162	< 1	11.3
Haiti	9720	143	< 1		127	< 1	0.86	Maldives	395	81	< 1		67	< 1	0.23
Honduras	8250	137	< 1		122	< 1	1.1	Mali	14517	156	< 1		143	< 1	0.75
Hungary	9979	28	30	295	131	< 1	1.75	Malta	418	83	< 1		27	4	1.67
Iceland	318	80	< 1		46	1	0.33	Marshall Islands	68	66	< 1		52	< 1	0.053
India	1203710	41	11	13065	195	< 1	75	Mauritania	3069	109	< 1		91	< 1	0.91
Indonesia	238400	196	< 1	1.4	194	< 1	20	Mauritius	1286	95	< 1		48	1	1.3
Iran	75330	56	1	100	183	< 1	4.3	Mexico	112323	54	5	519	188	< 1	4
Iraq	30400	178	< 1		167	< 1	2.2	Micronesia	111	72	< 1		58	< 1	0.045
Ireland	4581	5	312	1428	104	< 1	0.6	Moldova	3560	111	< 1		95	< 1	0.16
Israel	7826	135	< 1	6	24	5	40.2	Monaco	35.986	64	< 1		50	< 1	0
Italy	59394	16	98	5797	7	58	3457	Mongolia	2755	106	< 1	1.3	42	1	3.1
Jamaica	2847	42	10	29.7	88	< 1	0.43	Montenegro	625	86	< 1		71	< 1	0
Japan	127960	34	18	2304	9	28	3622	Morocco	32209	44	9	286	168	< 1	16.8
Jordan	6407	130	< 1	1.5	116	< 1	0.79	Mozambique	22894	167	< 1		156	< 1	1.2
Kazakhstan	16600	161	< 1	0.5	148	< 1	0.29	Myanmar (Burma)	60280	186	< 1		179	< 1	0.71
Kenya	41071	182	< 1		173	< 1	8.7	Namibia	2109	105	< 1	0.2	43	1	2.3
Kiribati	103.5	70	< 1		37	1	0.15	Nauru	10.175	60	< 1		28	4	0.04
Kosovo	1826	100	< 1		84	< 1	0	Nepal	29331	176	< 1		165	< 1	3.2
Kuwait	3566	112	< 1		96	< 1	1.8	Netherlands	17000	7	133	2261	23	6	97
Kyrgyzstan	5482	124	< 1		109	< 1	0.02	New Zealand	4414	11	115	506	40	1	5.5
Laos	6200	133	< 1		114	< 1	0.68	Nicaragua	6071	48	7	40	113	< 1	2.2
Latvia	2230	38	14	31	87	< 1	0.1	Niger	15731	159	< 1		146	< 1	0.8
Lebanon	4224	116	< 1		100	< 1	0.71	Nigeria	155215	193	< 1	2.2	190	< 1	11.6
Lesotho	2067	104	< 1		86	< 1	0.01	North Korea	24051	169	< 1		158	< 1	2.2
Liberia	3787	115	< 1		99	< 1	0.89	Norway	4989	17	88	434.6	36	1	7.3
Libya	5671	125	< 1		111	< 1	2.2	Oman	3609	113	< 1		97	< 1	0.7
Liechtenstein	36.1	65	< 1		4	119	4.3	Pakistan	178007	195	< 1	6	192	< 1	4
Lithuania	3201	24	48	154	92	< 1	0.1	Palau	20.956	62	< 1		26	5	0.1
Palestine	4261	117	< 1		101	< 1	0	Sudan	40000	179	< 1		172	< 1	2.1
Panama	3406	110	< 1		93	< 1	0.78	Suriname	529	85	< 1		70	< 1	0.48

State	Populati- on, 1000	Wind Rank	Wind C, W/c	Wind C, MW	Solar Rank	Solar C, W/c	Solar I, MW	State	Populati- on, 1000	Wind Rank	Wind C, W/c	Wind C, MW	Solar Rank	Solar C, W/c	Solar I, MW
Papua New Guinea	6858	127	< 1		119	< 1	1	Swaziland	1185	93	< 1		78	< 1	0.34
Paraguay	6455	131	< 1		117	< 1	0.06	Sweden	9415	6	230	2163	44	1	10
Peru	29496	177	< 1	1	166	< 1	10.2	Switzerland	7870	51	5	42.3	16	14	110
Philippines	94013	191	< 1	33	187	< 1	12.3	Syria	22717	166	< 1	0	155	< 1	0.84
Poland	38187	29	29	1107	171	< 1	1.8	Taiwan	23175	32	22	519	39	1	29
Portugal	10571	3	381	4030	18	12	130	Tajikistan	7996	136	< 1		121	< 1	0.33
Qatar	1697	98	< 1		82	< 1	1.2	Tanzania	43739	183	< 1		175	< 1	2.9
Romania	21905	31	27	591	153	< 1	1.94	Thailand	66720	187	< 1	0	180	< 1	46.5
Russia	141927	192	< 1	15	189	< 1	35.7	Timor-Leste	1067	92	< 1		77	< 1	0
Rwanda	11370	149	< 1		136	< 1	0.75	Togo	6619	132	< 1		118	< 1	0.93
Saint Kitts and Nevis	51.3	25	43	2	51	< 1	0	Tonga	104	71	< 1		56	< 1	0.096
Saint Lucia	173.8	75	< 1		61	< 1	0	Trinidad and Tobago	1228	94	< 1		79	< 1	0.14
Saint Vincent and the Grenadines	120	73	< 1		59	< 1	0	Tunisia	10433	52	5	54	134	< 1	3.2
Samoa	179	76	< 1		62	< 1	0	Turkey	73723	36	17	1274	182	< 1	6.2
San Marino	31.887	63	< 1		49	< 1	0	Turkmenistan	5110	121	< 1		107	< 1	0.13
Sao Tome and Principe	163	74	< 1		60	< 1	0.01	Tuvalu	10.544	61	< 1		29	4	0.04
Saudi Arabia	27137	171	< 1		160	< 1	9.1	Uganda	32370	180	< 1		169	< 1	4.9
Senegal	13712	153	< 1		140	< 1	4.7	Ukraine	44888	55	2	87.4	176	< 1	8.7
Serbia	7121	134	< 1		120	< 1	0.48	United Arab Emirates	8264	138	< 1		34	2	15.5
Seychelles	84	67	< 1		54	< 1	0.05	United Kingdom	62262	19	84	5204	45	1	66
Sierra Leone	5613	129	< 1		110	< 1	0.3	Uruguay	3495	45	9	31	94	< 1	2
Singapore	5184	122	< 1		108	< 1	3	USA	311722	8	128	40180	20	8	2528
Slovakia	5440	123	< 1	3	10	27	145	Uzbekistan	27606	172	< 1		161	< 1	0.23
Slovenia	2050	102	< 1		13	18	36	Vanuatu	243	39	12	3	63	< 1	0
Solomon Islands	523	84	< 1		69	< 1	0.32	Vatican City State	0.993	59	< 1		1	224	0.222
Somalia	9926	146	< 1		130	< 1	0.08	Venezuela	29106	174	< 1		163	< 1	2.6
South Africa	50587	185	< 1	10	178	< 1	39.5	Vietnam	90549	190	< 1	31	186	< 1	7.2
South Korea	48875	46	8	379	17	13	642	Yemen	23580	168	< 1		157	< 1	0.29
Spain	46667	2	443	20676	6	81	3784	Zambia	12935	151	< 1		138	< 1	1.3
Sri Lanka	20238	163	< 1		151	< 1	6.7	Zimbabwe	12521	150	< 1		137	< 1	3