Supporting Information

Unlocking the impacts of COVID-19 Lockdowns: Changes in Thermal Electricity Generation Water Footprint and Virtual Water Trade in Europe

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Additional remarks on the methodology: temporal changes of water footprint and virtual water in Europe

In this section, we describe the methodology that we implemented to quantify the temporal changes of water footprint (WF) and virtual water (VW) in Europe and for the five selected countries (Italy, Spain, France, Germany, and Switzerland) during the COVID-19 lockdowns. At the European level, we also disaggregate the portion of change possibly due to changes in electricity generation during the COVID-19 lockdowns, from the portion of change due to different electricity mix.

We applied the following methodology to the following variables of interest:

- 2020 time series of water footprint of electricity generation for Europe, DE, CH, IT, FR or ES
- 2020 time series of total virtual water imports to DE, CH, IT, FR or ES
- 2020 time series of total virtual water exports from DE, CH, IT, FR or ES

Given the time series of one of the analyzed variables of interest (V), (e.g., the 2020 time series of water footprint of electricity generation in Europe; see blue line in Figure S1), its average values in 2020 before and after the start of lockdown-like measures are compared to its average baseline values, i.e., the average values of the same variable V computed over the past four years (2016-2019). The average temporal change of the variable of interest (D in Equation S1 and Figure S1) is then calculated as a difference between the anomalies of its 2020 average values and the average 2016-2019 baseline values, before and after the lockdown-like measure start date.

$$D = \left(\overline{B_{bf}} - \overline{V_{bf}}\right) - \left(\overline{B_{af}} - \overline{V_{af}}\right) \quad \text{(S1)}$$

where $\overline{V_{bf}}$ is the mean value of V before the lockdown-like measures, $\overline{B_{bf}}$ is the mean value for the 2016-2019 baseline time series calculated over the same period of the year considered for $\overline{V_{bf}}$, $\overline{V_{af}}$ is the mean value of V after the lockdown-like measures, and $\overline{B_{af}}$ is the mean value for the baseline calculated over the same period of the year of $\overline{V_{af}}$. D thus represents the temporal change of variable V that occurred during the lockdown. Given that it is calculated as a difference of two anomalies referred to the same baseline, we can assume that it is cleaned from the main seasonality and inter-annual changes in electricity mix between 2016 and 2020. The value of D for any variable shows the actual change of water footprint or virtual water trade in m^3/day. Any relative value given as a percentage only indicates an order of magnitude that depends on the considered reference value; the true corrected value is subject to seasonal weather influences, considering that electricity generation and, therefore, also water footprints decrease in spring due to the warmer weather.[1,2] In this work, we considered the average between the 2016-19 and 2020 mean time series as baseline value. We applied Equation S1 for the calculation of the temporal change of the above-mentioned variables of interest both at the European level and for each of the selected countries.

For the analysis of the COVID-19 lockdown period at the European level, we also disaggregated the changes in the WF due to daily changes in the electricity mix, from the portion of change possibly due, to changes in electricity generation and demand. We chose a similar approach as Equation S1, where the changes due to a varying electricity mix are calculated as the difference between the variable of interest before the lockdown in 2020 and its 2016-2019 baseline. We modeled the changes due to electricity mix after the lockdown-like measures by comparison with a scenario where the electricity mix was fixed throughout the lockdown at the values from March 15, 2020. This analysis was implemented as follows and all variables are schematically represented in Figure S1:

- First, we shifted the variable of interest V by a term that takes into account seasonality and changes in electricity mix between 2016 and 2020 (as in Equation S1). The obtained shifted variable X (red line in Figure S1) is calculated as:

$$X = V + \left(\overline{B_{bf}} - \overline{V_{bf}}\right) \quad \text{(S2)}$$

- Second, we projected the shifted variable X to Y (green line in Figure S1). Y simulates X in the scenario where we fix the electricity mix during the lockdown to the date of the start of the lockdown (March 15, 2020). We therefore simulate the lockdown period assuming the same electricity mix each day, in order to disaggregate only the changes due to decreasing electricity generation in the lockdown period.
- Once X and Y are obtained and their average value is calculated for the lockdown period ($\overline{X_{af}}$, $\overline{Y_{af}}$), the two key variables d_1 and d_2 can be obtained, where d_1 represents the average water footprint change due to changes in daily electricity mix and d_2 represents the average change due to reduction in energy generation and is, thus, independent from changes in the electricity mix:

$$d_1 = \overline{Y_{af}} - \overline{X_{af}} \quad \text{(S3)}$$

$$d_2 = \overline{B_{af}} - \overline{Y_{af}} \quad \text{(S4)}$$

We can thus also conclude the following, considering the formulation of Equation S1 and approximation errors:

$$D \approx d_1 + d_2 \quad \text{(S5)}$$

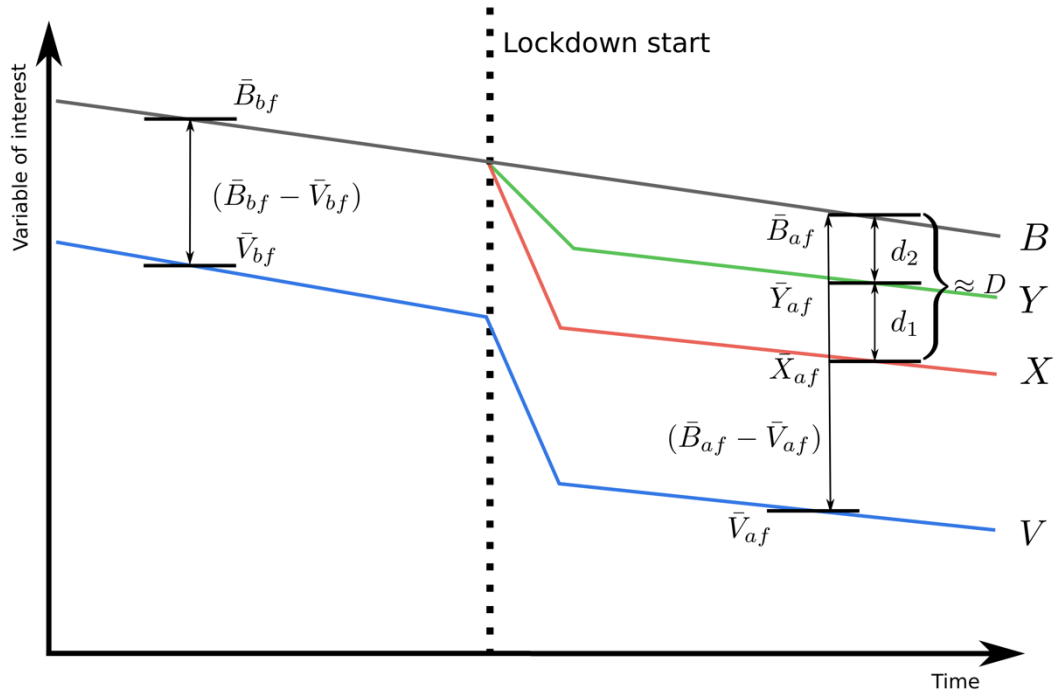

Figure S1: Schematic representation of the variable of interest (V, blue line), its Baseline (B, grey line), and all the variables formulated in the methodological section. This schematic representation is only provided for visualization purposes.

Finally, we calculated the water footprint of electricity load for DE, CH, IT, FR, and ES as:

$$WF_{electricity\ load} = WF_{electricity\ generation} + VW_{import} - VW_{export} \quad \text{(S6)}$$

Table S1: Specific water consumption (m^3/MWh) for different electricity producing technologies and cooling water technologies based on[3] and described in[4]. The values were taken from the JRC-PPDB-OPEN and its average values were used in this study. For solar, the value 0 was used as the only deviation from the database. Photovoltaic solar panels require a negligible amount of water during operations. In the JRC-PPDB-OPEN[5] only 36 out of 278 (13%) of facilities consume water for cooling (all of them in Spain and probably all concentrated solar power). In this study we thus neglected the water footprint of solar.

	Air Cooling	Mechanical Draught Tower	Natural Draught Tower	Once-through	Unknown	Average
Biomass	0.13	2.09	2.09	1.14	-	**1.36**
Fossil Brown coal/Lignite	0.22	1.81	1.81/1.87	0.95	2.06/0.16	**1.27**
Fossil Coal derived gas	0.1	3.13	3.13	0.38/0.91	-	**1.53**
Fossil Gas	0.01/0.1	0.78/3.13	0.78/3.13	0.38/0.91	0.78/0.91	**1.09**
Fossil Hard coal	0.22	1.81/1.87	1.81/1.87	0.39/0.95	2.06	**1.37**
Fossil Oil	0.1	3.13	3.13	0.91	-	**1.82**
Fossil Oil shale	-	-	-	0.95	-	**0.95**
Fossil Peat	-	1.81	1.81	0.95	-	**1.52**
Geothermal	0.02	0.06	0.06	-	-	**0.05**
Nuclear	-	2.54	2.54	1.02	-	**2.03**
Other	0.1	3.13	3.13	0.91	-	**1.82**
Waste	0.13	2.09	2.09	1.14	-	**1.36**
Solar	-	-	-	3.43	-	**0.00**
Wind Onshore	-	-	-	-	-	**0.00**
Wind Offshore	-	-	-	-	-	**0.00**
Other renewable	-	-	-	-	-	**0.00**
Marine	-	-	-	-	-	**0.00**
Hydro Water Reservoir	-	-	-	-	-	**0.00**
Hydro Run-of-river and poundage	-	-	-	-	-	**0.00**
Hydro Pumped Storage	-	-	-	-	-	**0.00**

Table S2: Countries included in/excluded from this study due to incomplete datasets for 2020.

Country	Code	Included
Albania	AL	No
Austria	AT	Yes
Belarus	BY	No
Belgium	BE	Yes
Bosnia and Herzegovina	BA	Yes
Bulgaria	BG	Yes
Croatia	HR	No
Czech Republic	CZ	Yes
Denmark	DK	No
Estonia	EE	Yes
Finland	FI	Yes
North Macedonia	MK	No
France	FR	Yes
Germany	DE	Yes
Greece	GR	Yes
Hungary	HU	Yes
Ireland	IE	No
Italy	IT	Yes
Latvia	LV	Yes
Lithuania	LT	Yes
Luxembourg	LU	No
Malta	MT	No
Montenegro	ME	No
Netherlands	NL	Yes
Norway	NO	Yes
Poland	PL	Yes
Portugal	PT	Yes
Republic of Moldova	MD	No
Romania	RO	Yes
Serbia	RS	Yes
Slovakia	SK	No
Slovenia	SI	Yes
Spain	ES	Yes
Sweden	SE	Yes
Switzerland	CH	Yes
United Kingdom	UK	Yes
Ukraine	UA	No
Cyprus	CY	No

Table S3: Start date of measures against the COVID-19 pandemic in the selected five countries.

Date	France	Germany	Switzerland	Italy	Spain
Precautionary Measures (PCM)	12-Mar-20[6]	15-Mar-20[7]	--	20-Feb-20[8]	--
Lockdown Measures (LDM)	24-Mar-20[9]	23-Mar-20[10]	16-Mar-20[11]	10-Mar-20[8]	16-Mar-20[12]

Table S4: COVID-19 cases and deaths in selected European countries as of March 15, 2020. The table is sorted by absolute cases, which was our basis for selecting the five top countries. The gray areas show the top five countries in the other categories.

Country	Absolute Cases[6]	Cases relative to population[13,14]	Absolute Deaths[13]
Italy	**24747**	**0.41‰**	**6820**
Spain	**7798**	**0.17‰**	**2808**
Germany	**5795**	0.07‰	157
France	**4499**	0.07‰	**1100**
Switzerland	**2200**	**0.26‰**	122
Norway	1221	**0.23‰**	12
United Kingdom	1140	0.02‰	**422**
Netherlands	1135	0.07‰	**276**
Sweden	1022	0.10‰	36
Belgium	886	0.08‰	122
Austria	860	0.10‰	28
Greece	331	0.03‰	20
Czech Republic	253	0.02‰	3
Portugal	245	0.02‰	33
Finland	244	0.04‰	1
Slovenia	219	0.11‰	4
Estonia	171	**0.13‰**	0
Ireland	129	0.03‰	7
Poland	119	0.00‰	10
Slovakia	54	0.01‰	0
Bulgaria	51	0.01‰	3
Serbia	48	0.01‰	3
Hungary	32	0.00‰	9
Bosnia and Herzegovina	24	0.01‰	3
Lithuania	12	0.00‰	2

Table S5: Changes in virtual water trade during lockdowns in 1000 m^3/day.

	To IT	To CH	To DE	To ES	To FR	To other
From IT	0	2.6	0	0	0.2	0.8
From CH	-47.4	0	30.5	0	-0.4	7.1
From DE	0	-0.6	0	0	-2.1	0.5
From ES	0	0	0	0	1.2	9.9
From FR	-22.8	-1.5	16.2	9.6	0	1.5
From Others	-0.5	0.2	-6.4	-3.9	11.5	0

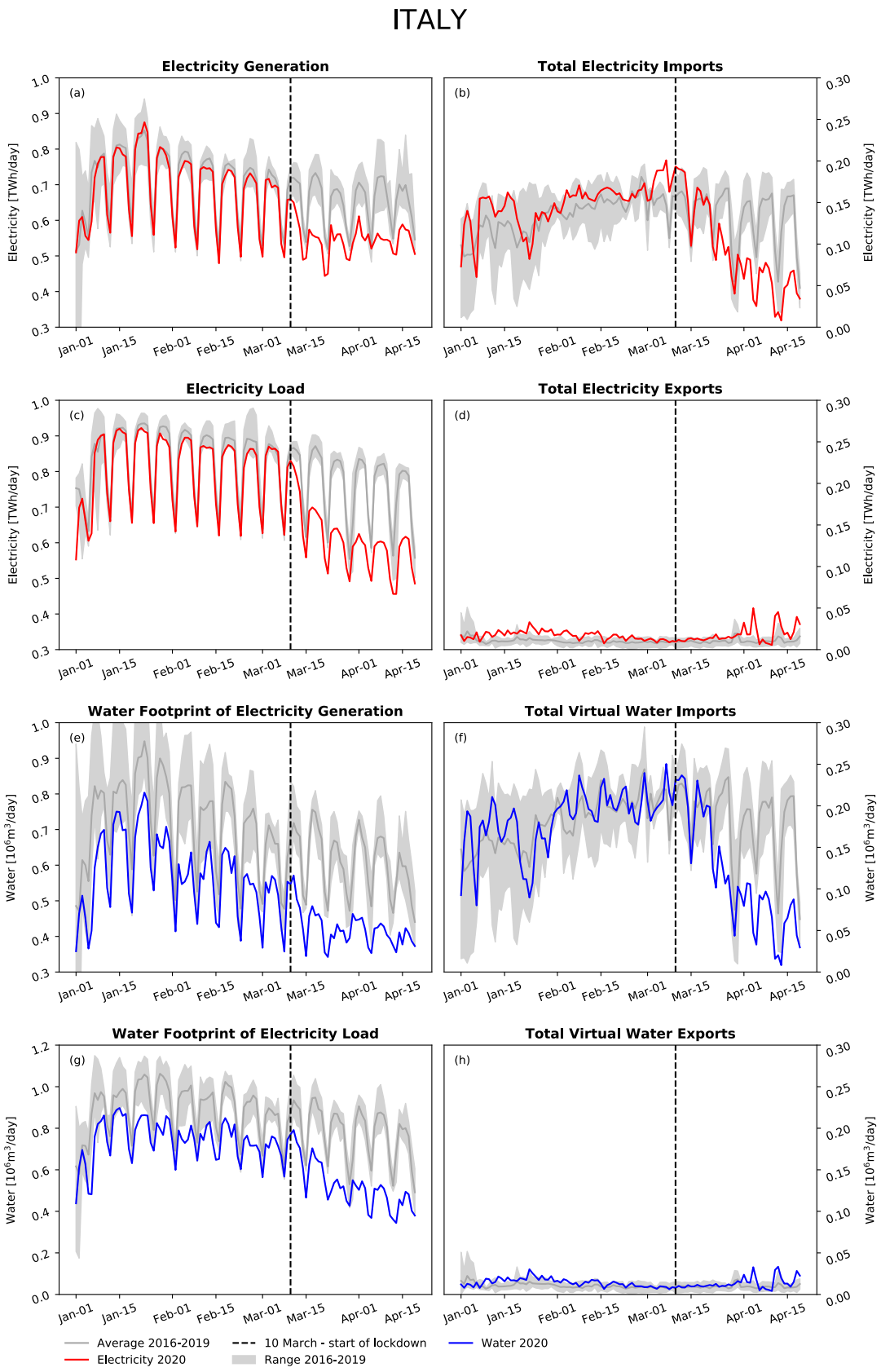

Figure S2: ITALY. Electricity generation, load, imports, and exports (red lines) and related Water Footprint and Virtual Water time series (blue lines) in Italy from January 1, 2020 to April 19, 2020. Time series are compared to their average values and minimum-maximum range since 2016 (gray line and shaded gray area). The dotted black line shows the start of the lockdown in Italy on March 10, 2020.

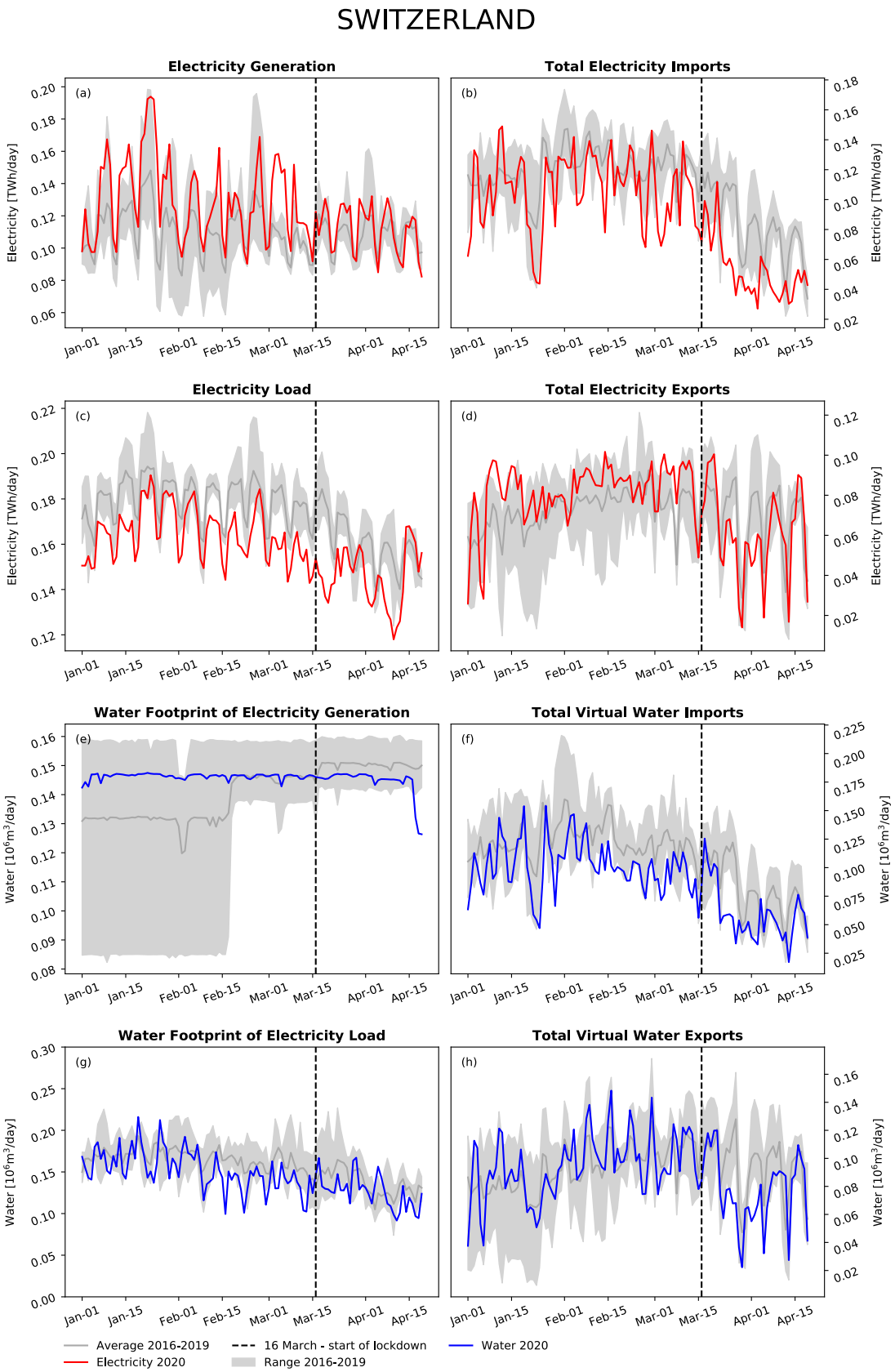

Figure S3: SWITZERLAND. Electricity generation, load, imports, and exports (red lines) and related Water Footprint and Virtual Water time series (blue lines) in Switzerland from January 1, 2020 to April 19, 2020. Time series are compared to their average values and minimum-maximum range since 2016 (gray line and shaded gray area). The dotted black line shows the start of the lockdown in Switzerland on March 16, 2020.

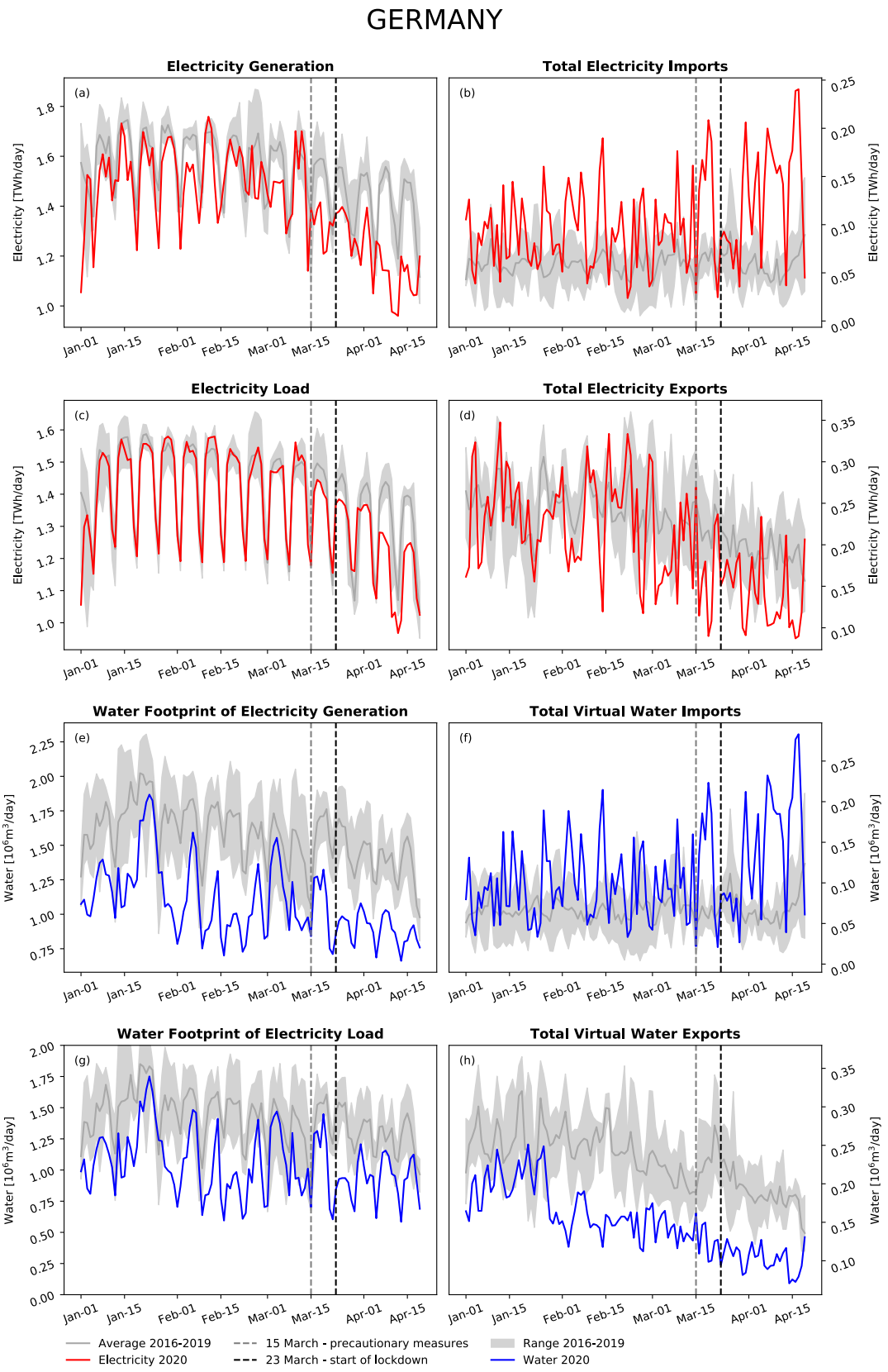

Figure S4: GERMANY. Electricity generation, load, imports, and exports (red lines) and related Water Footprint and Virtual Water time series (blue lines) in Germany from January 1, 2020 to April 19, 2020. Time series are compared to their average values and minimum-maximum range since 2016 (gray line and shaded gray area). The dotted gray line shows the start of preventive measures on March 15,2020, and the dotted black line shows the start of the lockdown on March 23, 2020.

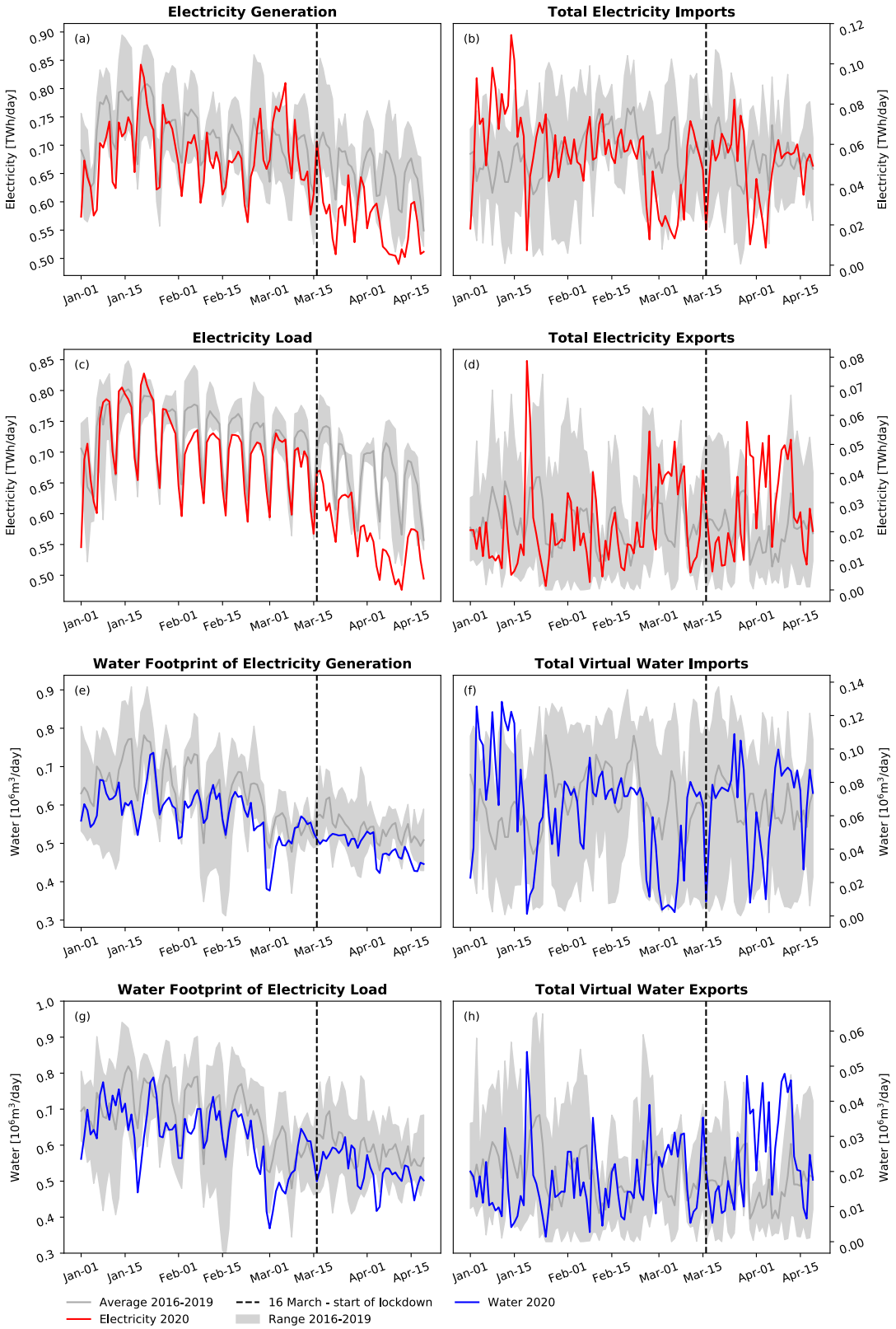

Figure S5: SPAIN. Electricity generation, load, imports, and exports (red lines) and related Water Footprint and Virtual Water time series (blue lines) in Spain from January 1, 2020 to April 19, 2020. Time series are compared to their average values and minimum-maximum range since 2016 (gray line and shaded gray area). The dotted black line shows the start of the lockdown Spain on March 16, 2020.

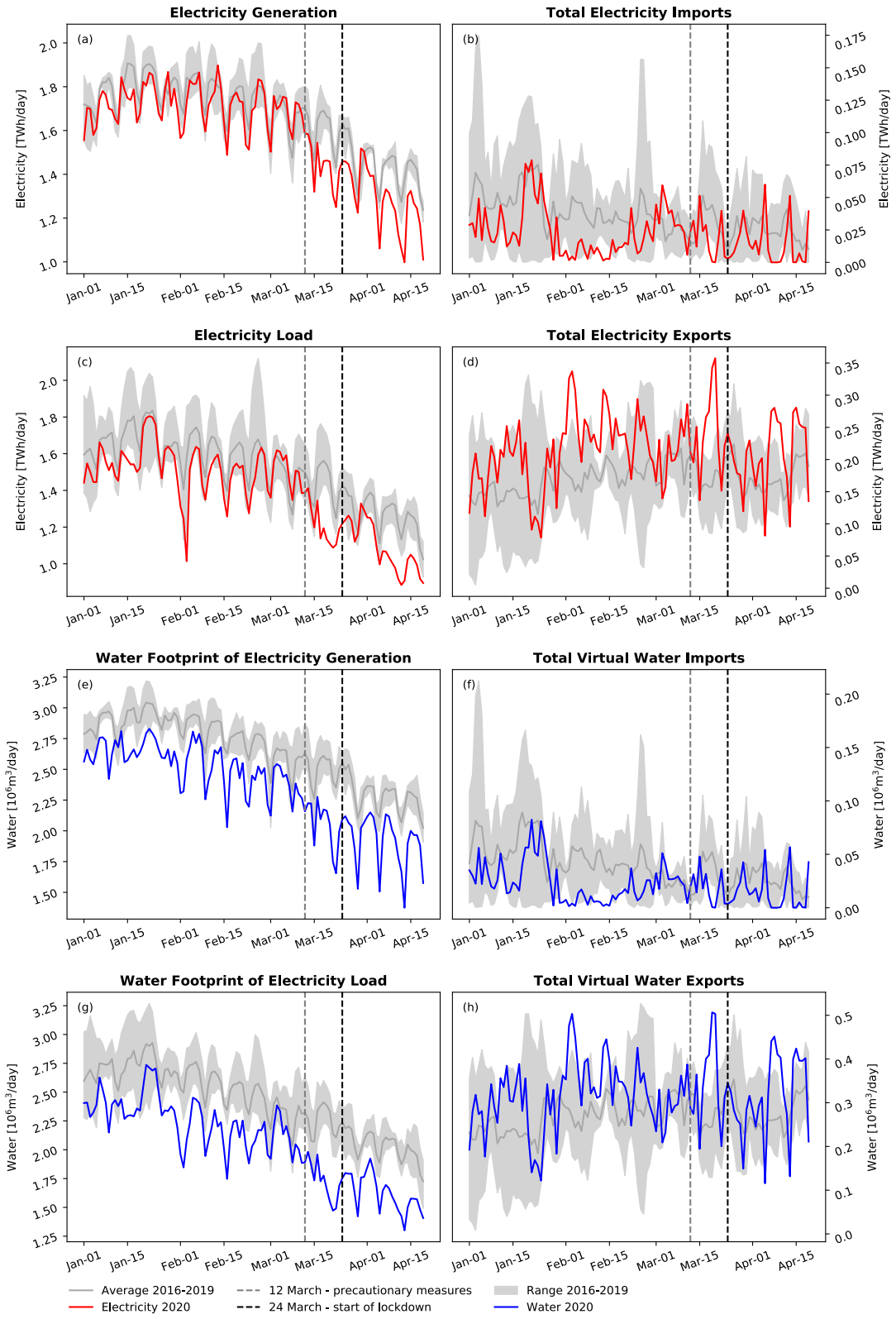

Figure S6: FRANCE. Electricity generation, load, imports, and exports (red lines) and related Water Footprint and Virtual Water time series (blue lines) in France from January 1, 2020 to April 19, 2020. Time series are compared to their average values and minimum-maximum range since 2016 (gray line and shaded gray area). The dotted gray line shows the start of preventive measures on March 10, 2020, and the dotted black line shows the start of the lockdown on March 24, 2020.

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