Supplementary material to "Anthropogenic and natural methane fluxes within Switzerland synthesized in a spatially-explicit inventory"

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S1 Emission factors

S1.1 Lakes and reservoirs

CH_4 emissions from lakes and reservoirs were determined based on the following equations by Bastviken et al. (2004) in units of gC lake^{-1} yr^{-1}:

$$Ebullition\,(E) = 10^{1.190 + 0.841 \times \log 10(area)}, \quad (S1)$$

$$Diffusion(D) = 10^{0.234 + 0.927 \times \log 10(area)}, \quad (S2)$$

$$Storage(S) = 10^{1.546 + 0.649 \times \log 10(area)}. \quad (S3)$$

Table S1 shows how the equations were combined to estimate the total CH_4 flux of the lake or reservoir, depending on its depth and elevation.

Table S1: Formula to calculate total CH_4 flux for lakes and reservoirs depending on their depth, elevation, and surface area. Formula variables based on Section S1.1 above. Area and F_{CH4} indicate the total surface area covered by and the total CH_4 flux from the different lake types, respectively.

Lake type	Depth [m]	Elevation [m a.s.l.]	Formula	Area [km^2]	Number of lakes	F_{CH4} [Gg CH_4 yr^{-1}]
Natural lakes	≤ 30	≤ 1500	F=3*(0.5*E+D+S)	10	29	0.07
Natural lakes	≤ 30	> 1500	F=3*(D+S)	2	15	0.01
Natural lakes	> 30	≤ 1500	F=0.5*E+D+S	1264	23	1.52
Natural lakes	> 30	> 1500	F=D+S	9	5	0.01
Reservoir	≤ 30	≤ 1500	F=3*(0.5*E+D+S)	14	12	0.08
Reservoir	≤ 30	> 1500	F=3*(D+S)	3	16	0.01
Reservoir	> 30	≤ 1500	F=0.5*E+D+S	42	22	0.08
Reservoir	> 30	> 1500	F=D+S	44	46	0.05
Undefined	≤ 30	≤ 1500	F=3*(0.5*E+D+S)	9	206	0.10
Undefined	≤ 30	> 1500	F=3*(D+S)	12	423	0.08

Lake type	Depth [m]	Elevation [m a.s.l.]	Formula	Area [km^2]	Number of lakes	F_{CH4} [Gg CH_4 yr^{-1}]
Undefined	> 30	≤ 1500	F=0.5*E+D+S	0	0	0.00
Undefined	> 30	> 1500	F=D+S	0	0	0.00
Lake Wohlen				3	1	0.20
Total				1412	798	2.21

42

43 S1.2 Wetlands

The determination of representative emission factors (EF) was challenging due to the small-scale nature of these ecosystems. Typical mires in Switzerland, for instance are expected to have only a few water statured depressions where emissions of 100–300 mg CH_4 m^{-2} d^{-1} occur while the surrounding area consists of rather well-aerated soils and vegetation. Hence, a per-hectare estimate may be composed of 5% of the flux expected from an ecosystem classified as fen and 95% of mostly upland regions which produce less CH_4 or may even uptake it. Therefore, a national inventory with a hectare resolution or coarser must use emission rate estimates that are aggregated in a way that realistically reflects the variability within the pixel. Best estimates used in our inventory for wetland sources at the aggregation level of available statistical land classifications range from as low as 0.42 mg CH_4 m^{-2} d^{-1} up to 221 mg CH_4 m^{-2} d^{-1} with an area weighted average of 2.67 mg CH_4 m^{-2} d^{-1}. These EFs rely on various literature studies as tabulated in

44 *Table S2.*

Table S2: Emission factors (EF) to calculate CH_4 flux for different wetland types. The data sets used for the determination of the wetland area are indicated with hm (Federal Inventory of Raised and Transition Bogs of National Importance; FOEN, 2008b), au (Federal Inventory of Floodplains of National Importance; FOEN, 2008a), fm (Federal Inventory of Fens of National Importance; FOEN, 2010), and ren (National Ecological Network REN, wetland site; FOEN, 2011). Additional information on the determination of the EF is given in the columns reference and remarks.

Wetland type	Data set	Area	EF	F_{CH4}	Reference	Remarks
		[km^{-2}]	[mg CH_4 m^{-2} d^{-1}]	[Gg CH_4 yr^{-1}]		
Saturated raised bogs	hm	0.32	221	0.026	Rask et al. (2002)	Center of “deep bay” fen
String bogs	hm	0.63	196	0.045	Corradi et al. (2005)	
Transitional mires	hm	13.13	119	0.570	Rask et al. (2002)	“shallow bay” fen
Lake shores	au	19.7	59	0.424	Delsontro et al. (2010)	
Hummocky raised bogs	hm	3.66	96	0.128	Simpson et al. (1997)	
Birch and spruce muskegs	hm	2.55	5.6	0.004	Ullah and Moore (2011)	Hemlock
River deltas	au	8.69	36	0.114	Ullah and Moore (2011)	Inbetween
Raised bogs with mixed vegetation	hm	5.24	2.1	0.004	Ullah and Moore (2011)	Riparian forest
Open water bodies	hm	0.25	15	0.001	Delsontro et al. (2010)	Diffusive flux only
Exploited peatlands	hm	0.43	60	0.009	Rask et al. (2002)	“flark” fen
Alpine	au	4.44	6.5	0.011		50% of running

Wetland type	Data set	Area [km^{-2}]	EF [mg CH_4 m^{-2} d^{-1}]	F_{CH4} [Gg CH_4 yr^{-1}]	Reference	Remarks
floodplains						waters
Glacier forelands	au	88.62	3.7	0.120		50% of running waters
Running waters and streams	au	99.87	13	0.480	Bastviken et al. (2011)	
Tall forb communitites	hm	0.5	1	0.000		50% of running waters
Gardens in settlements	hm	0.05	3.6	0.000	Boldrin et al. (2009)	Home composting
Mountain pine muskegs	hm	3.52	1	0.001		50% of raised bogs with mixed vegetation
Dolines	hm	0	2.1	0.000	Ullah and Moore (2011)	Riparian forest
Unspecified mires	fm	165.5	0.63	0.038		150% of unspecified wetlands
Unspecified wetlands	ren	1901	0.42	0.291	Ullah and Moore (2011)	20% of Riparian forests
Total		2318.1		2.266		

S1.3 Wild animals

Table S3: Emission factors to calculate CH_4 emissions from wild animals taken from SAEFL (1996). Additionally, the habitat area based on land-use statistics (FSO GEOSTAT, 2009) as well as the estimated CH_4 fluxes are given.

Species	Population	EF [kg animal^{-1} year^{-1}]	Habitat area [km^2]	F_{CH4} [Gg CH_4 yr^{-1}]
Red dear	30,000	14	11,000	0.42
Roe deer	119,000	2.3	10,500	0.27
Alpine Chamois	94,000	3	2,500	0.28
Alpine ibex	17,000	6	5,000	0.10
Total	260,000		29,000	1.07

S1.4 Forest soils

Table S4: Emission factors to calculate CH_4 uptake by forest soils for different forest types following Hobi (2011). Additionally, the forest area as well as the estimated CH_4 flux is given.

Forest type	EF [mg CH_4 m^{-2}]	Area [km^2]	F_{CH4} [Gg CH_4 yr^{-1}]
Deciduous	−1.12	500	−0.21
Evergreen	−0.46	2,200	−0.37
Mixed	−1.10 to −0.47	8,500	−2.24
Total		11,200	−2.82

S2 Population density in Switzerland

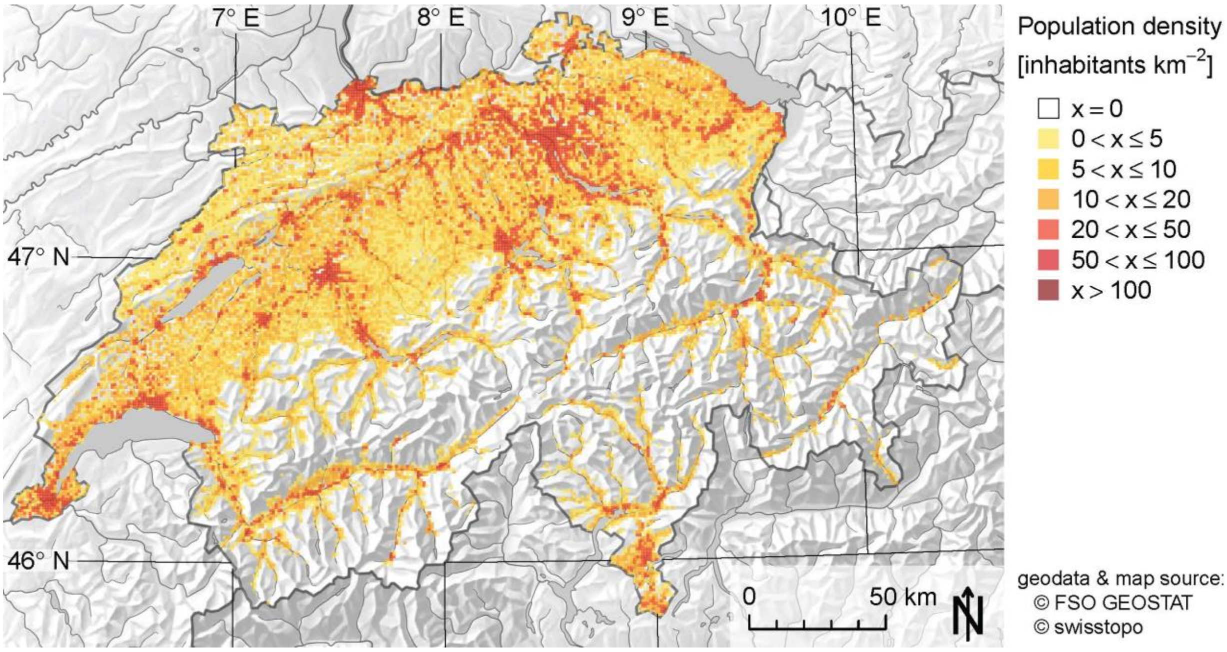

Figure S1: Swiss population density (FSO GEOSTAT, 2012)

References

Bastviken, D., Cole, J., Pace, M. and Tranvik, L.: Methane emissions from lakes: Dependence of lake characteristics, two regional assessments, and a global estimate, Global Biogeochem. Cy., 18(4), doi:10.1029/2004GB002238, 2004.

Bastviken, D., Tranvik, L. J., Downing, J. A., Crill, P. M. and Enrich-Prast, A.: Freshwater methane emissions offset the continental carbon sink, Science, 331(6013), 50 2011.

Boldrin, A., Andersen, J. K., Moller, J., Christensen, T. H. and Favoino, E.: Composting and compost utilization: accounting of greenhouse gases and global warming contributions, Waste Manage. Res., 27(8), 800–812 2009.

Corradi, C., Kolle, O., Walter, K., Zimov, S. A. and Schulze, E. D.: Carbon dioxide and methane exchange of a north-east Siberian tussock tundra, Glob. Change Biol., 11(11), 1910–1925, doi:10.1111/j.1365-2486.2005.01023.x, 2005.

DelSontro, T., McGinnis, D. F., Sobek, S., Ostrovsky, I. and Wehrli, B.: Extreme methane emissions from a Swiss hydropower reservoir: contribution from bubbling sediments, Environ. Sci. Technol., 44(7), 2419–25, doi:10.1021/es9031369, 2010.

FOEN: Bundesinventar der Auengebiete von nationaler Bedeutung, Federal Office for the Environment (FOEN), [online] Available from: http://www.bafu.admin.ch/gis/02911/07403/index.html?lang=de (Accessed 28 March 2013a), 2008.

FOEN: Bundesinventar der Hoch- und Übergangsmoore von nationaler Bedeutung, Federal Office for the Environment (FOEN), [online] Available from: http://www.bafu.admin.ch/gis/02911/07403/index.html?lang=de (Accessed 28 March 2013b), 2008.

FOEN: Bundesinventar der Flachmoore von nationaler Bedeutung, Federal Office for the Environment (FOEN), [online] Available from: http://www.bafu.admin.ch/gis/02911/07403/index.html?lang=de (Accessed 28 March 2013), 2010.

FOEN: Nationales ökologisches Netzwerk (REN: Lebensraum Feuchtgebiet), Federal Office for the Environment (FOEN), [online] Available from: http://www.bafu.admin.ch/gis/02911/07403/index.html?lang=de (Accessed 28 March 2013), 2011.

FSO GEOSTAT: Population and household statistics, (STATPOP) 2011, ha-grid, Federal Statistical Office (FSO), 2012.

FSO GEOSTAT: Land use statistics. (Arealstatistik) 1992/97, ha-grid, Federal Statistical Office (FSO), 2009.

Hobi, S.: Spatial allocation of methane sources and sinks in Switzerland, 76 pp., ETH Zurich. 2011.

Rask, H., Schoenau, J. and Anderson, D.: Factors influencing methane flux from a boreal forest wetland in Saskatchewan, Canada, Soil Biol. Biochem., 34(4), 435–443 2002.

SAEFL: Luftschadstoff-Emissionen aus natürlichen Quellen in der Schweiz, in Schriftenreihe Umwelt - Luft, vol. 257, Swiss Agency for the Environment, Forests and Landscape (SAEFL), 1996.

Simpson, I. J., Edwards, G. C., Thurtell, G. W., Den Hartog, G., Neumann, H. H. and Staebler, R. M.: Micrometeorological measurements of methane and nitrous oxide exchange above a boreal aspen forest, J. Geophys. Res.-Atmos., 102(D24), 29331–29341 1997.

Ullah, S. and Moore, T. R.: Biogeochemical controls on methane, nitrous oxide, and carbon dioxide fluxes from deciduous forest soils in eastern Canada, J. Geophys. Res., 116(G3), 1–15, doi:10.1029/2010JG001525, 2011.