**Supplementary materials**

for the paper “Environmental tradeoffs of agricultural growth in Russian regions and possible sustainable pathways for 2030”, by Anton Strokov[1] and Vladimir Potashnikov

Figure S1. Value of agricultural production in agricultural organizations of Russia (CXO) in 2019, bln RUB

| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
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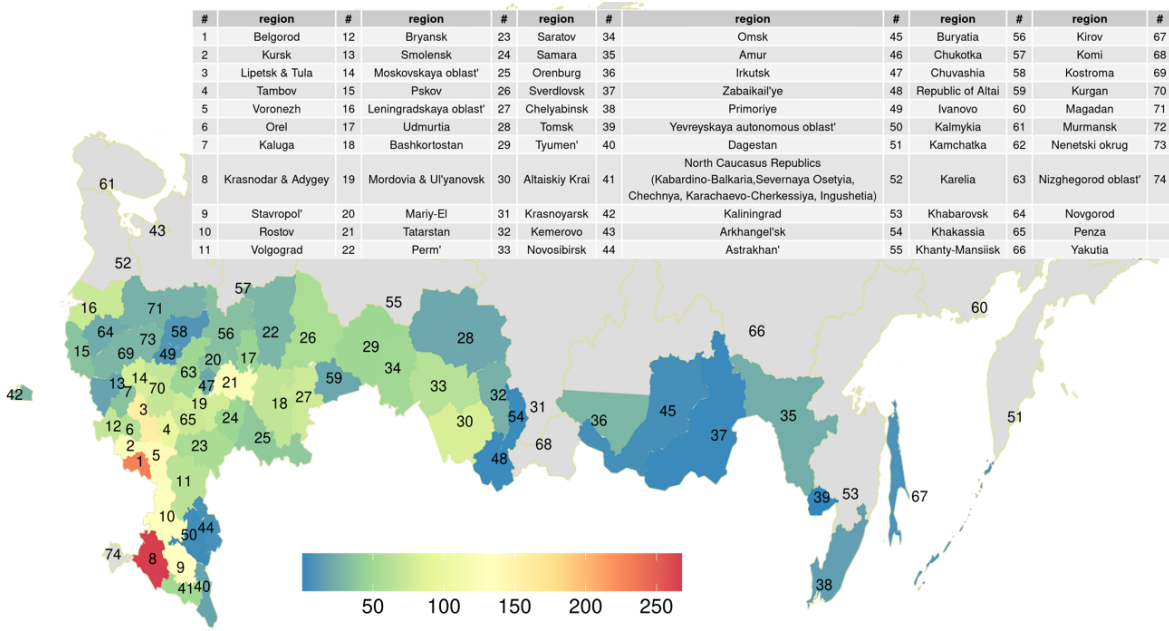


Source: Rosstat

Figure S2. Waste from agricultural production in 2019, thousand tons

| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
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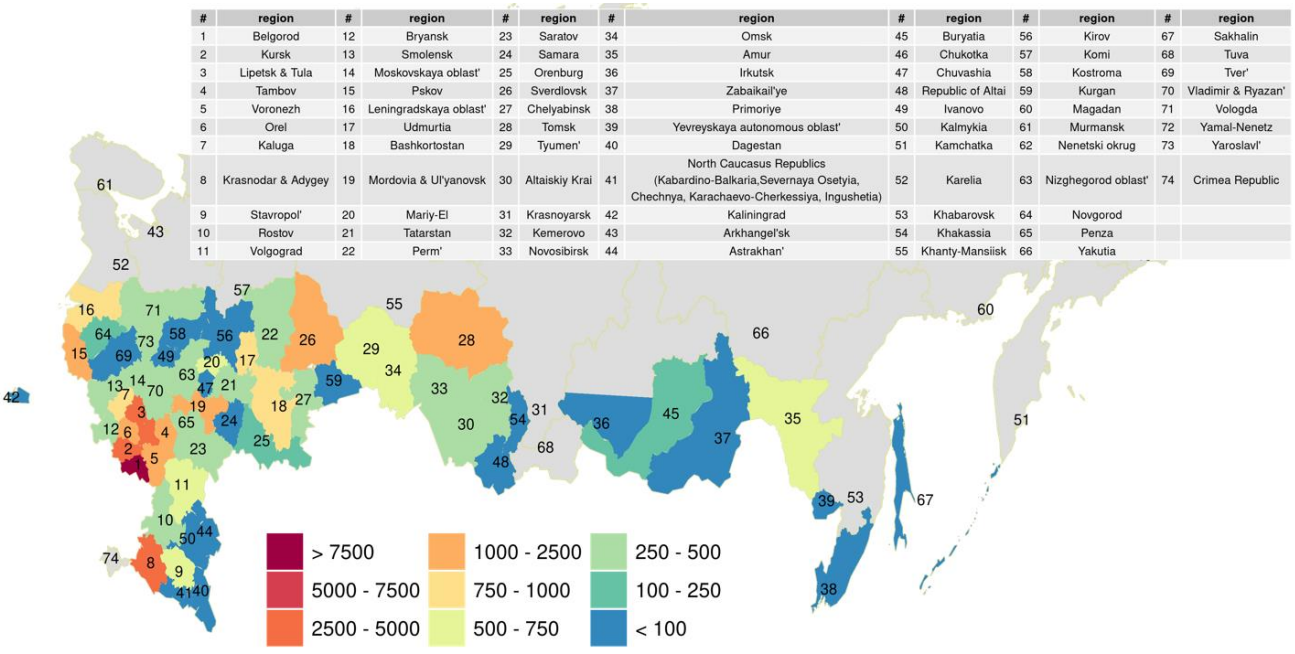


Source: Rosprirodnadzor

[1] Anton Strokov is the author responsible for correspondence. E-mail: strokov-as@ranepa.ru.

Figure S3. Waste-agricultural value ratio, kg per thousand rubles

| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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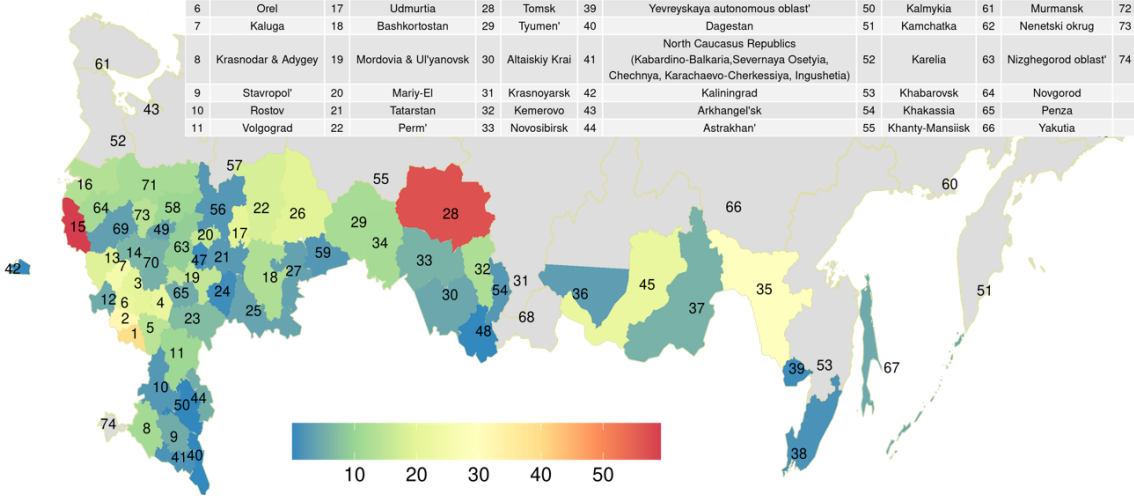


Source: authors calculation using data of Rosstat and Rosprirodnadzor

Figure S4. Nitrogen excretion from livestock manure in 2019 from main agricultural animals, thousand tons of N

| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
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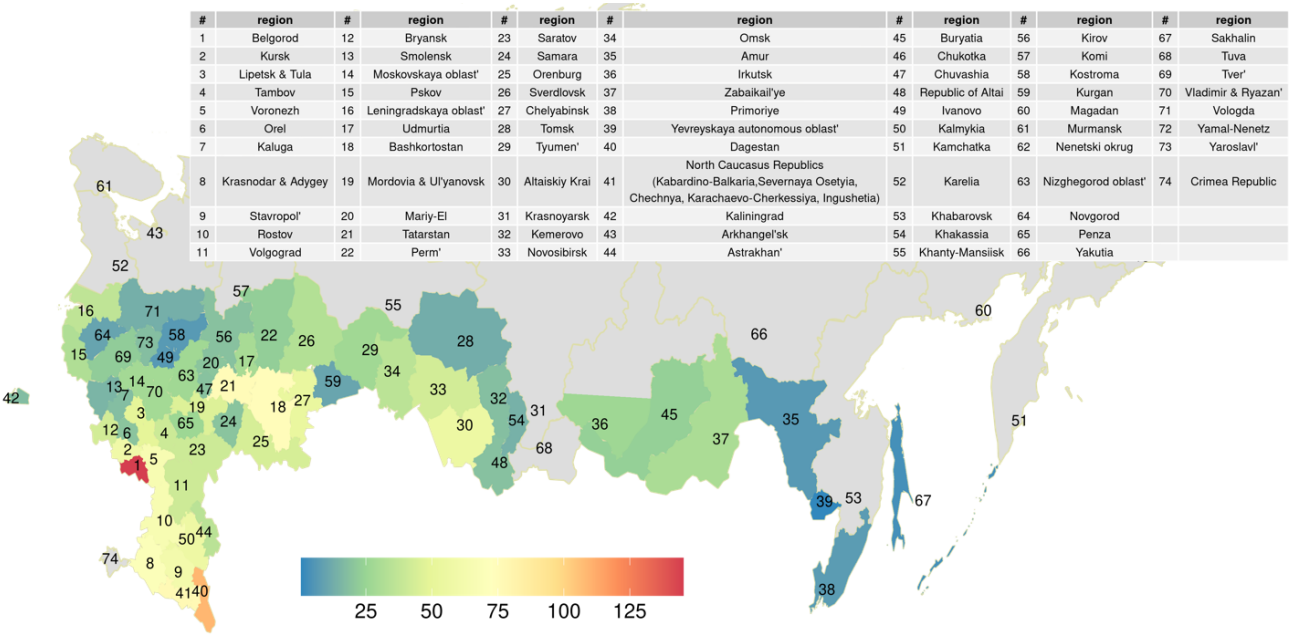
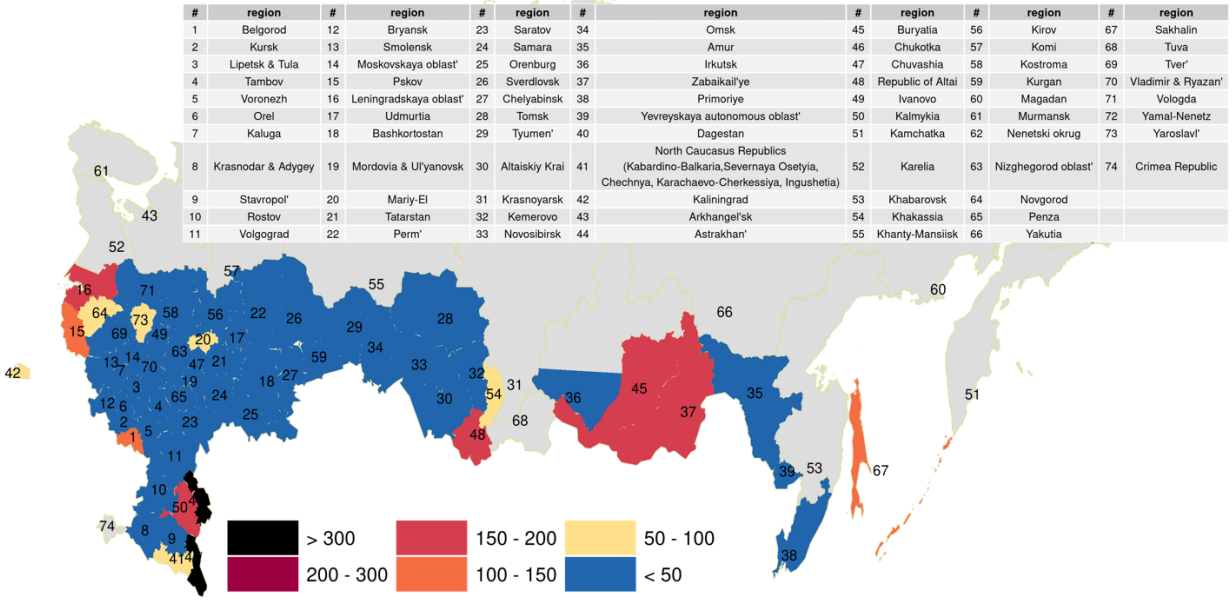



Source: authors calculations based on livestock herd data from Rosstat and nitrogen excrection data of different livestock type from Russian National Greenhouse Gas Inventories (IGCE, 2021).

Notes: includes data on the number of herd in all type of Russian farms for selected types of animals: cow, other cattle, pig, sheep, and all poultry.

Figure S5. Nitrogen concentration per hectare of cultivated cropland in 2019, kg N / ha

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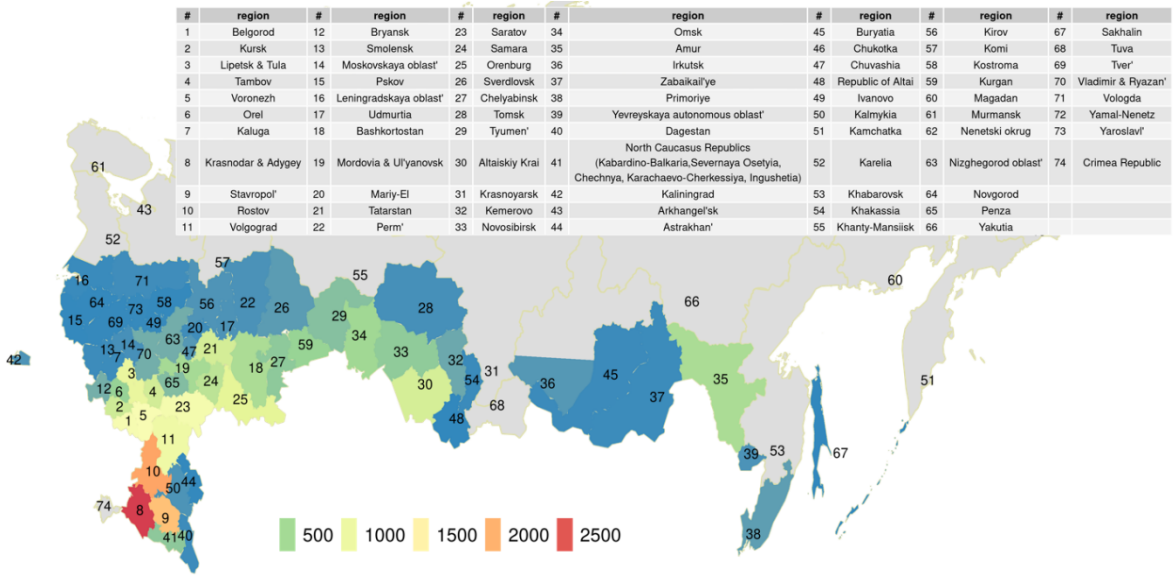
Source: authors calculations based on data from Rosstat and Russian National Greenhouse Gas Inventories

In the next figures only GLOBIOM results are presented.

Figure S6. Crop production in Russian regions in 2019, thousand metric tons of crude protein equivalent

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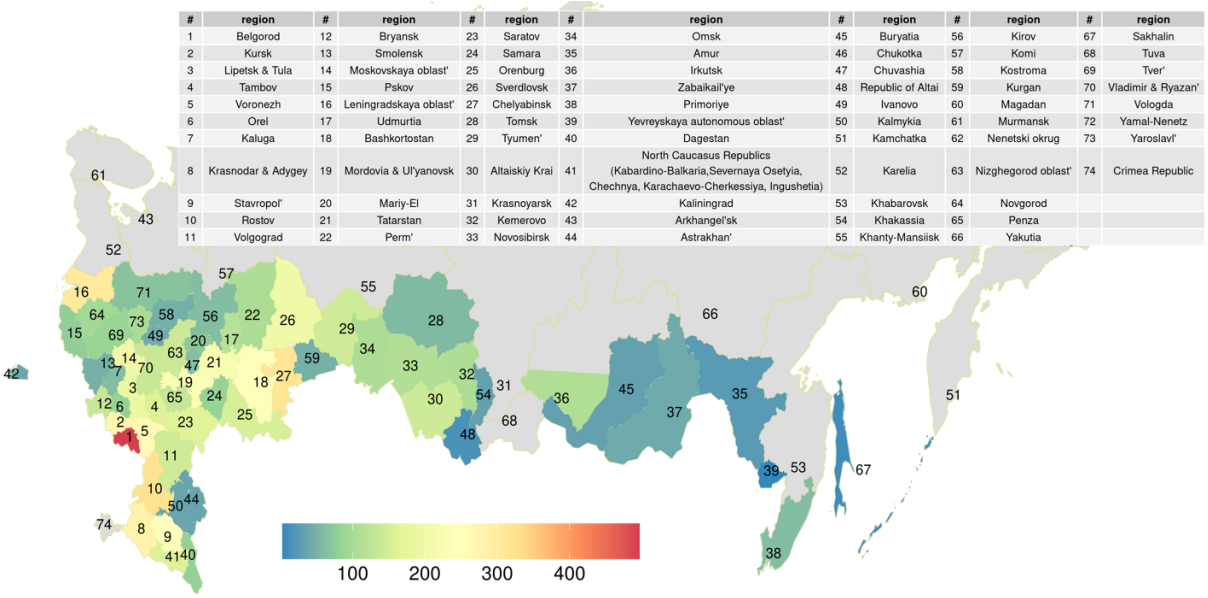
Source: authors estimates with GLOBIOM model

Notes: for calibration of the GLOBIOM model we used data of Rosstat for selected crops, and after the model's calculation converted to particular protein equivalent based on data from Fuglie (2015): wheat 0.142, rice 0.076, barley 0.119, corn 0.096, millet 0.116, sorghum 0.111, pulses 0.226, potato 0.022, and for oilseed (soy, sunflower and rapeseed) 0.392.

Figure S7. Livestock production in 2019, thousand metric tons of crude protein equivalent

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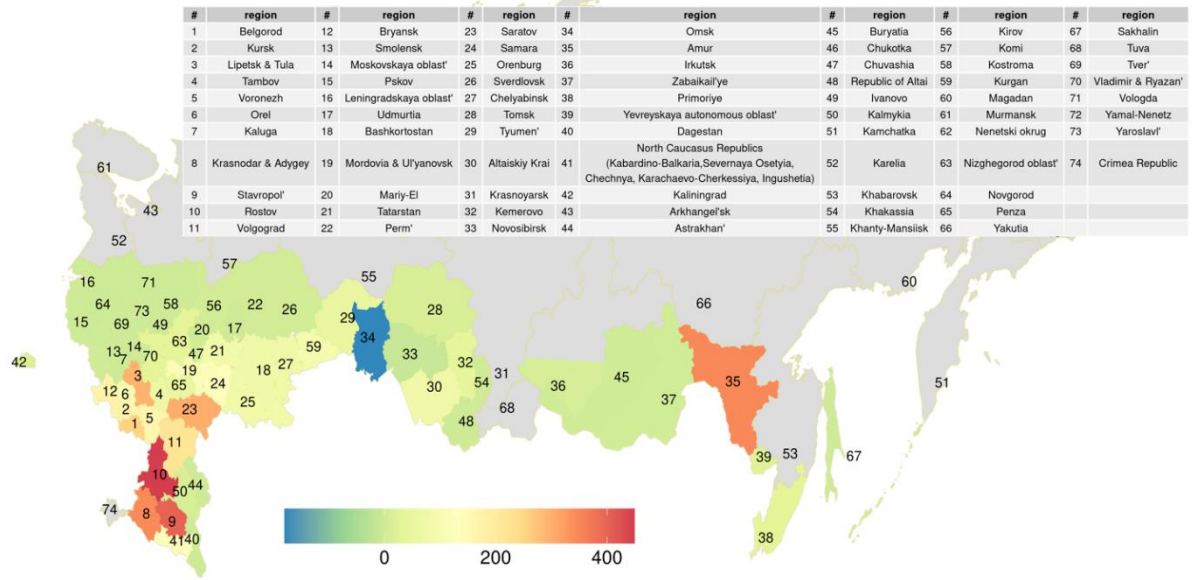
Source: authors estimates with GLOBIOM model

Notes: for calibration of the GLOBIOM model we used data of Rosstat for selected products of meat, milk and eggs, and after the model's calculation converted to particular protein equivalent based on data from Fuglie (2015): meat (beef, pork, poultry, sheep) 0.514, cow milk 0.033, egg 0.514.

Figure S8. Cropland expansion 2019 relative to 2011, thousand ha

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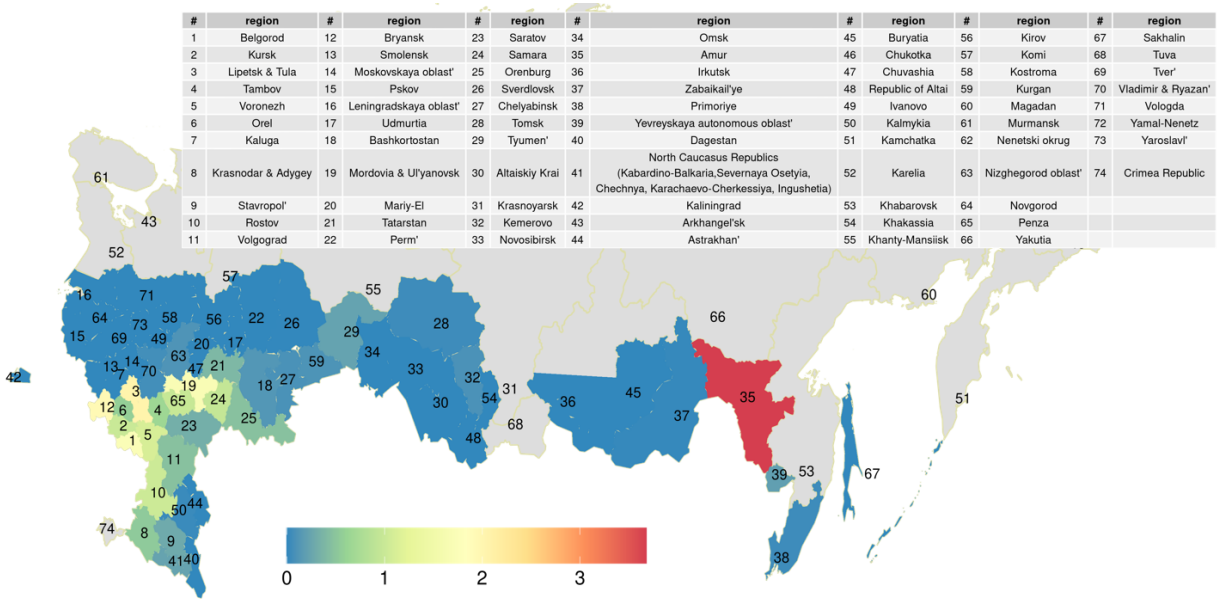
Source: authors estimates with GLOBIOM model

Figure S9. Land use change (LUC) greenhouse gas emissions only from cropland expansion in 2019, million tons of CO2

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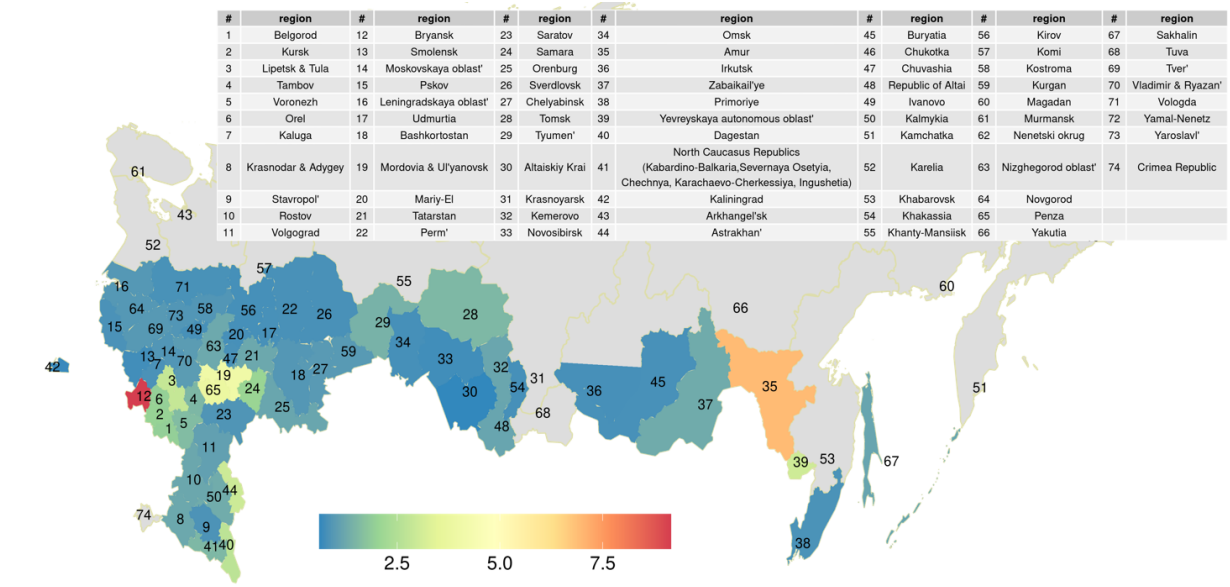
Source: authors estimates with GLOBIOM model

Figure S10. Carbon footprint for crop production. Particularly GHG emissions (including LUC emissions) for crop protein production in 2019, ton CO2eq / ton protein

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| 7 | Kaluga | 18 | Bashkortostan | 29 | Tyumen' | 40 | Dagestan | 51 | Kamchatka | 62 | Nenetski okrug | 73 | Yaroslavl' |
| 8 | Krasnodar & Adygey | 19 | Mordovia & Ul'yanovsk | 30 | Altaiskiy Krai | 41 | North Caucasus Republics (Kabardino-Balkaria,Severnaya Osetyia, Chechnya, Karachaevo-Cherkessiya, Ingushetia) | 52 | Karelia | 63 | Nizghegorod oblast' | 74 | Crimea Republic |
| 9 | Stavropol' | 20 | Mariy-El | 31 | Krasnoyarsk | 42 | Kaliningrad | 53 | Khabarovsk | 64 | Novgorod | | |
| 10 | Rostov | 21 | Tatarstan | 32 | Kemerovo | 43 | Arkhangel'sk | 54 | Khakassia | 65 | Penza | | |
| 11 | Volgograd | 22 | Perm' | 33 | Novosibirsk | 44 | Astrakhan' | 55 | Khanty-Mansiisk | 66 | Yakutia | | |

Source: authors estimates with GLOBIOM model

Figure S11. Carbon footprint of livestock. Particularly GHG emissions per livestock protein prodiction in 2019, ton CO2eq / ton protein

| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
| 2 | Kursk | 13 | Smolensk | 24 | Samara | 35 | Amur | 46 | Chukotka | 57 | Komi | 68 | Tuva |
| 3 | Lipetsk & Tula | 14 | Moskovskaya oblast' | 25 | Orenburg | 36 | Irkutsk | 47 | Chuvashia | 58 | Kostroma | 69 | Tver' |
| 4 | Tambov | 15 | Pskov | 26 | Sverdlovsk | 37 | Zabaikail'ye | 48 | Republic of Altai | 59 | Kurgan | 70 | Vladimir & Ryazan' |
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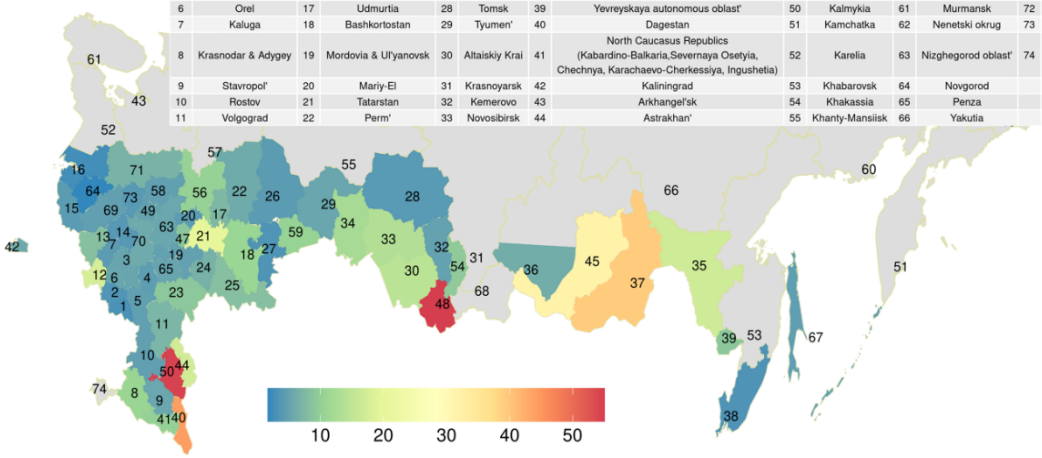
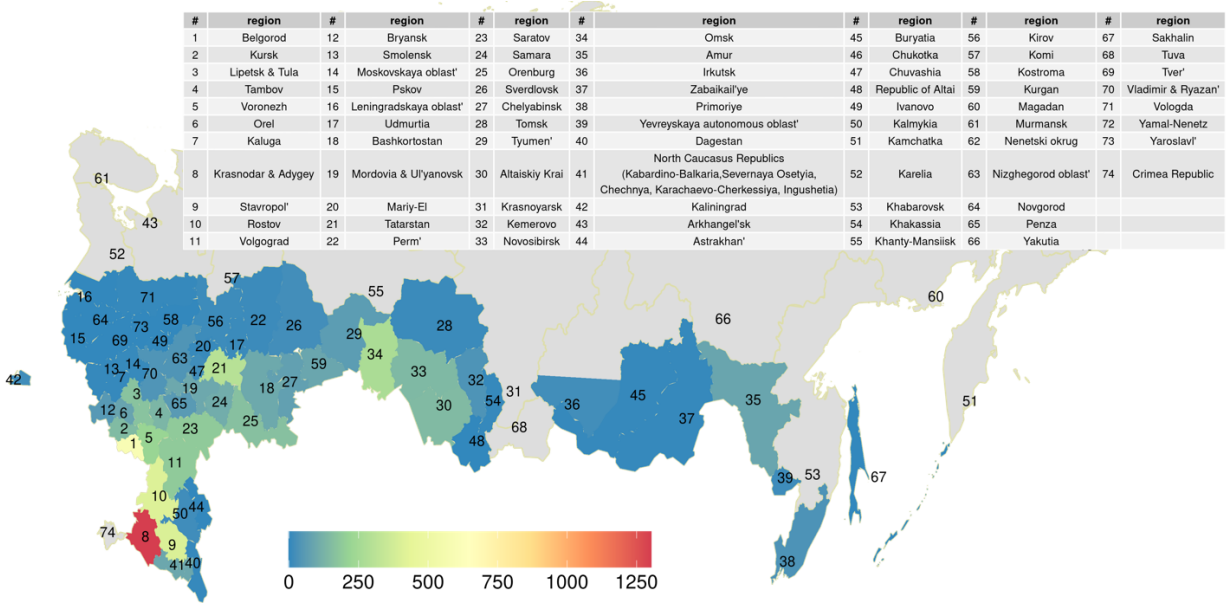
| 11 | Volgograd | 22 | Perm' | 33 | Novosibirsk | 44 | Astrakhan' | 55 | Khanty-Mansiisk | 66 | Yakutia | | |




Source: authors estimates with GLOBIOM model

Projections for 2030 using GLOBIOM.

Figure S12. Crop protein growth in 2030 relative to 2019 (extensive scenario), thousand tons




| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
| 2 | Kursk | 13 | Smolensk | 24 | Samara | 35 | Amur | 46 | Chukotka | 57 | Komi | 68 | Tuva |
| 3 | Lipetsk & Tula | 14 | Moskovskaya oblast' | 25 | Orenburg | 36 | Irkutsk | 47 | Chuvashia | 58 | Kostroma | 69 | Tver' |
| 4 | Tambov | 15 | Pskov | 26 | Sverdlovsk | 37 | Zabaikal'ye | 48 | Republic of Altai | 59 | Kurgan | 70 | Vladimir & Ryazan' |
| 5 | Voronezh | 16 | Leningradskaya oblast' | 27 | Chelyabinsk | 38 | Primoriye | 49 | Ivanovo | 60 | Magadan | 71 | Vologda |
| 6 | Orel | 17 | Udmurtia | 28 | Tomsk | 39 | Yevreyskaya autonomous oblast' | 50 | Kalmykia | 61 | Murmansk | 72 | Yamal-Nenetz |
| 7 | Kaluga | 18 | Bashkortostan | 29 | Tyumen' | 40 | Dagestan | 51 | Kamchatka | 62 | Nenetski okrug | 73 | Yaroslavl' |
| 8 | Krasnodar & Adygey | 19 | Mordovia & Ul'yanovsk | 30 | Altaiskiy Krai | 41 | North Caucasus Republics (Kabardino-Balkaria,Severnaya Osetyia, Chechnya, Karachaevo-Cherkessiya, Ingushetia) | 52 | Karelia | 63 | Nizghegorod oblast' | 74 | Crimea Republic |
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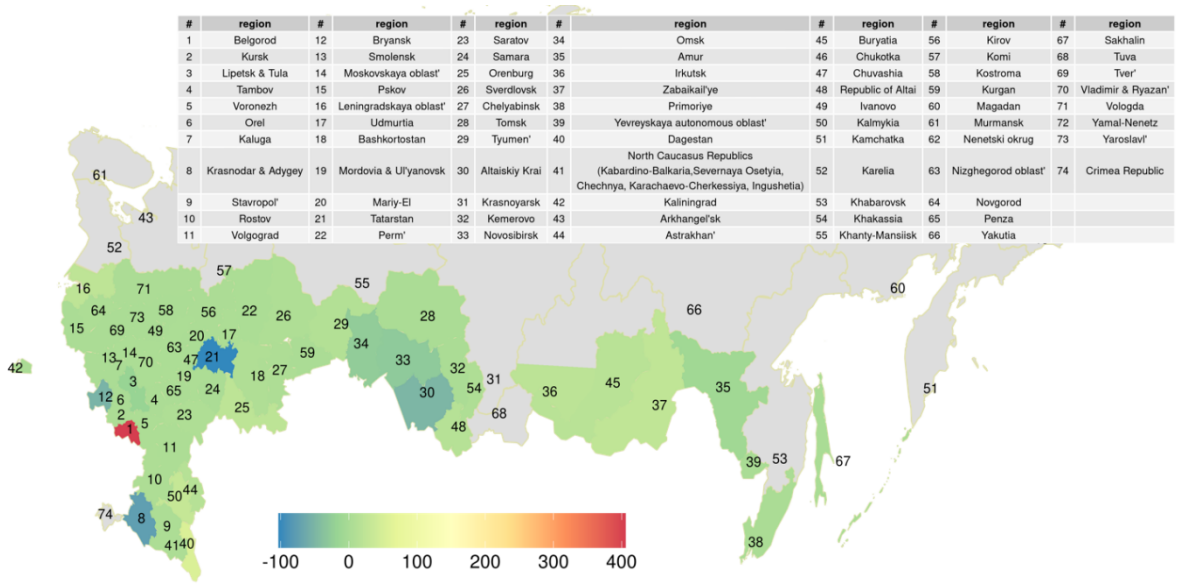
| 10 | Rostov | 21 | Tatarstan | 32 | Kemerovo | 43 | Arkhangel'sk | 54 | Khakassia | 65 | Penza | | |
| 11 | Volgograd | 22 | Perm' | 33 | Novosibirsk | 44 | Astrakhan' | 55 | Khanty-Mansiisk | 66 | Yakutia | | |

Source: authors estimates with GLOBIOM

Figure S13. Livestock protein growth in 2030 relative to 2019 (extensive scenario), thousand tons




| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
| 2 | Kursk | 13 | Smolensk | 24 | Samara | 35 | Amur | 46 | Chukotka | 57 | Komi | 68 | Tuva |
| 3 | Lipetsk & Tula | 14 | Moskovskaya oblast' | 25 | Orenburg | 36 | Irkutsk | 47 | Chuvashia | 58 | Kostroma | 69 | Tver' |
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| 11 | Volgograd | 22 | Perm' | 33 | Novosibirsk | 44 | Astrakhan' | 55 | Khanty-Mansiisk | 66 | Yakutia | | |

Source: authors estimates with GLOBIOM

Figure S14. Cropland growth in 2030 relative to 2019 (in extensive scenario), thousand ha

| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
| 2 | Kursk | 13 | Smolensk | 24 | Samara | 35 | Amur | 46 | Chukotka | 57 | Komi | 68 | Tuva |
| 3 | Lipetsk & Tula | 14 | Moskovskaya oblast' | 25 | Orenburg | 36 | Irkutsk | 47 | Chuvashia | 58 | Kostroma | 69 | Tver' |
| 4 | Tambov | 15 | Pskov | 26 | Sverdlovsk | 37 | Zabaikail'ye | 48 | Republic of Altai | 59 | Kurgan | 70 | Vladimir & Ryazan' |
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| 6 | Orel | 17 | Udmurtia | 28 | Tomsk | 39 | Yevreyskaya autonomous oblast' | 50 | Kalmykia | 61 | Murmansk | 72 | Yamal-Nenetz |
| 7 | Kaluga | 18 | Bashkortostan | 29 | Tyumen' | 40 | Dagestan | 51 | Kamchatka | 62 | Nenetski okrug | 73 | Yaroslavl' |
| 8 | Krasnodar & Adygey | 19 | Mordovia & Ul'yanovsk | 30 | Altaiskiy Krai | 41 | North Caucasus Republics (Kabardino-Balkaria,Severnaya Osetyia, Chechnya, Karachaevo-Cherkessiya, Ingushetia) | 52 | Karelia | 63 | Nizghegorod oblast' | 74 | Crimea Republic |
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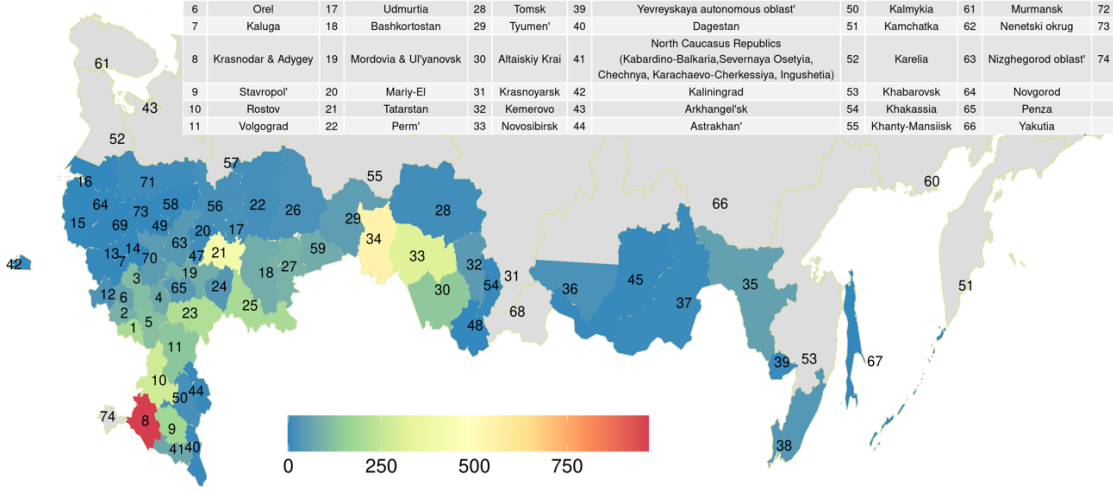
| 10 | Rostov | 21 | Tatarstan | 32 | Kemerovo | 43 | Arkhangel'sk | 54 | Khakassia | 65 | Penza | | |
| 11 | Volgograd | 22 | Perm' | 33 | Novosibirsk | 44 | Astrakhan' | 55 | Khanty-Mansiisk | 66 | Yakutia | | |




Source: authors estimates with GLOBIOM

Figure S15. GHG emissions from LUC from cropland expansion in 2030 (in extensive scenario), million tons of CO2

| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
| 2 | Kursk | 13 | Smolensk | 24 | Samara | 35 | Amur | 46 | Chukotka | 57 | Komi | 68 | Tuva |
| 3 | Lipetsk & Tula | 14 | Moskovskaya oblast' | 25 | Orenburg | 36 | Irkutsk | 47 | Chuvashia | 58 | Kostroma | 69 | Tver' |
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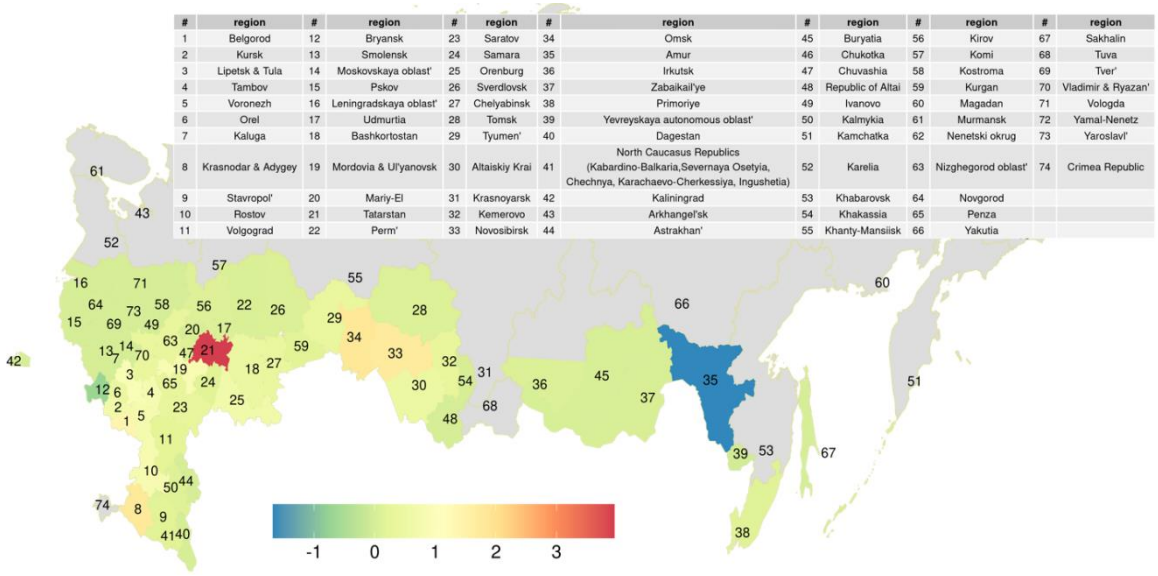
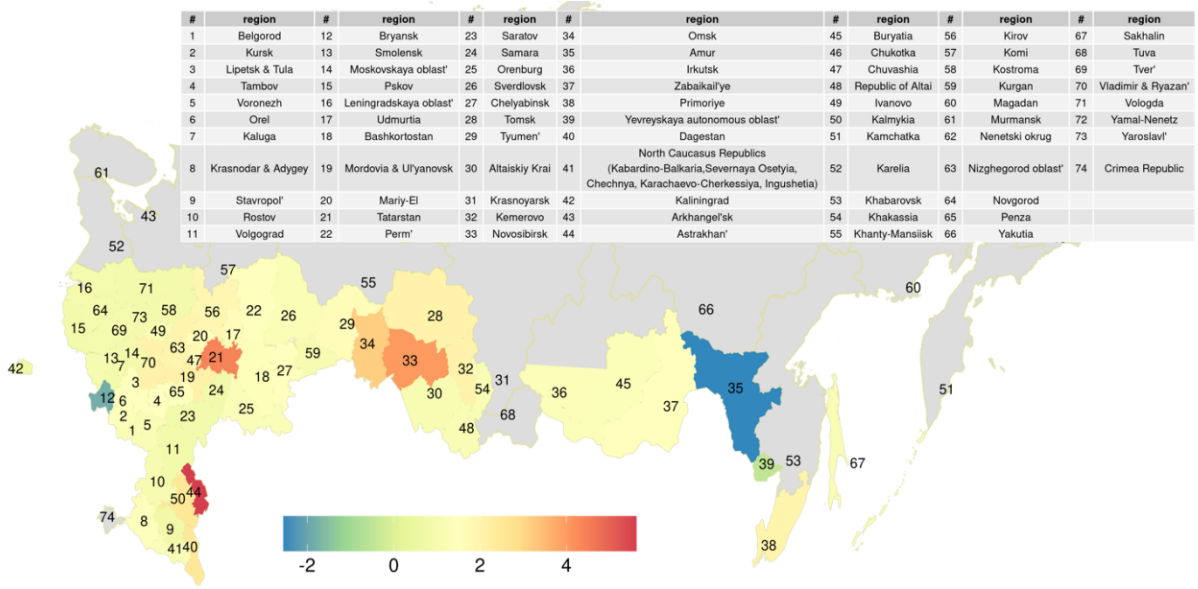
| 11 | Volgograd | 22 | Perm' | 33 | Novosibirsk | 44 | Astrakhan' | 55 | Khanty-Mansiisk | 66 | Yakutia | | |




Source: authors estimates with GLOBIOM

Figure S16. Crop GHG emission intensity in 2030 in land expansion (extensive) scenario, ton CO2eq/ ton crop protein




| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
| 2 | Kursk | 13 | Smolensk | 24 | Samara | 35 | Amur | 46 | Chukotka | 57 | Komi | 68 | Tuva |
| 3 | Lipetsk & Tula | 14 | Moskovskaya oblast' | 25 | Orenburg | 36 | Irkutsk | 47 | Chuvashia | 58 | Kostroma | 69 | Tver' |
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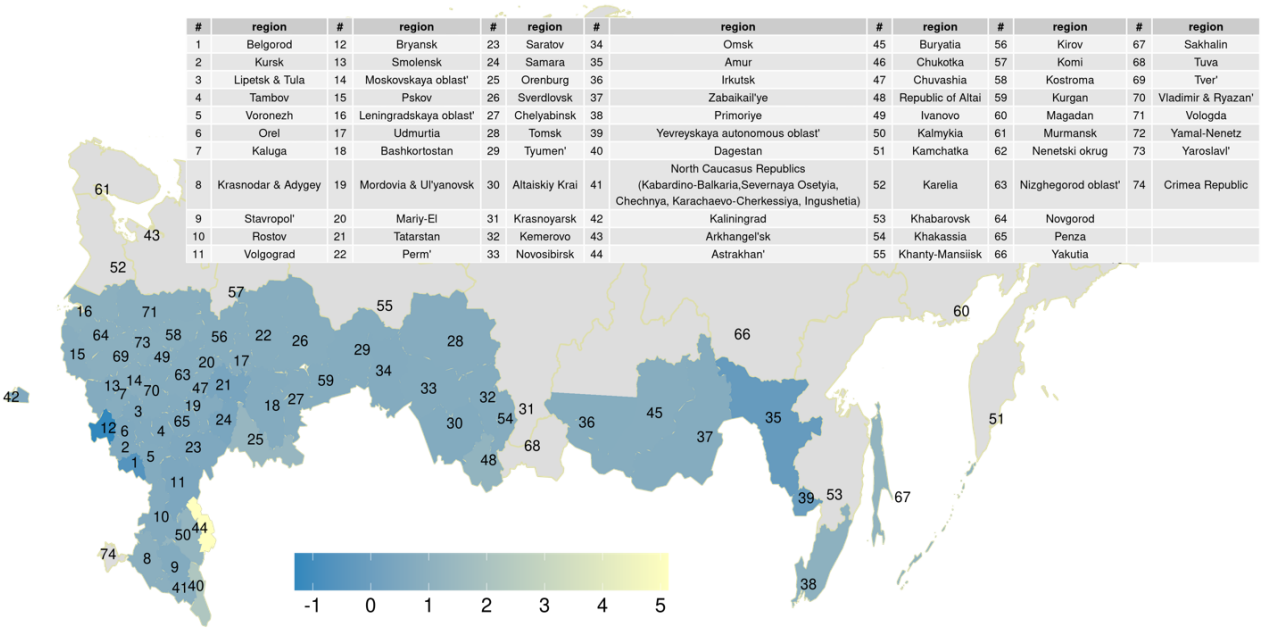
| 11 | Volgograd | 22 | Perm' | 33 | Novosibirsk | 44 | Astrakhan' | 55 | Khanty-Mansiisk | 66 | Yakutia | | |

Source: authors estimates with GLOBIOM

Figure S17. Crop GHG emission intensity in 2030 in intensive scenario, ton CO2eq / ton crop protein




| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
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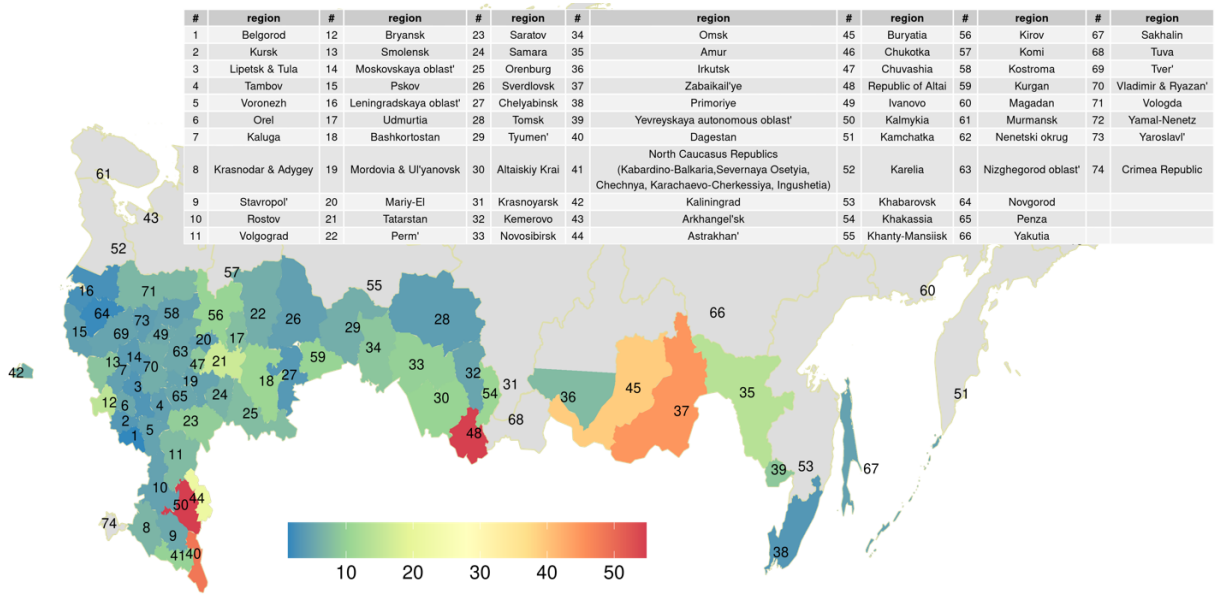
| 11 | Volgograd | 22 | Perm' | 33 | Novosibirsk | 44 | Astrakhan' | 55 | Khanty-Mansiisk | 66 | Yakutia | | |

Source: authors estimates with GLOBIOM

Figure S18. Livestock GHG emission intensity in 2030 in expansion scenario, ton CO2eq / ton livestock protein




| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
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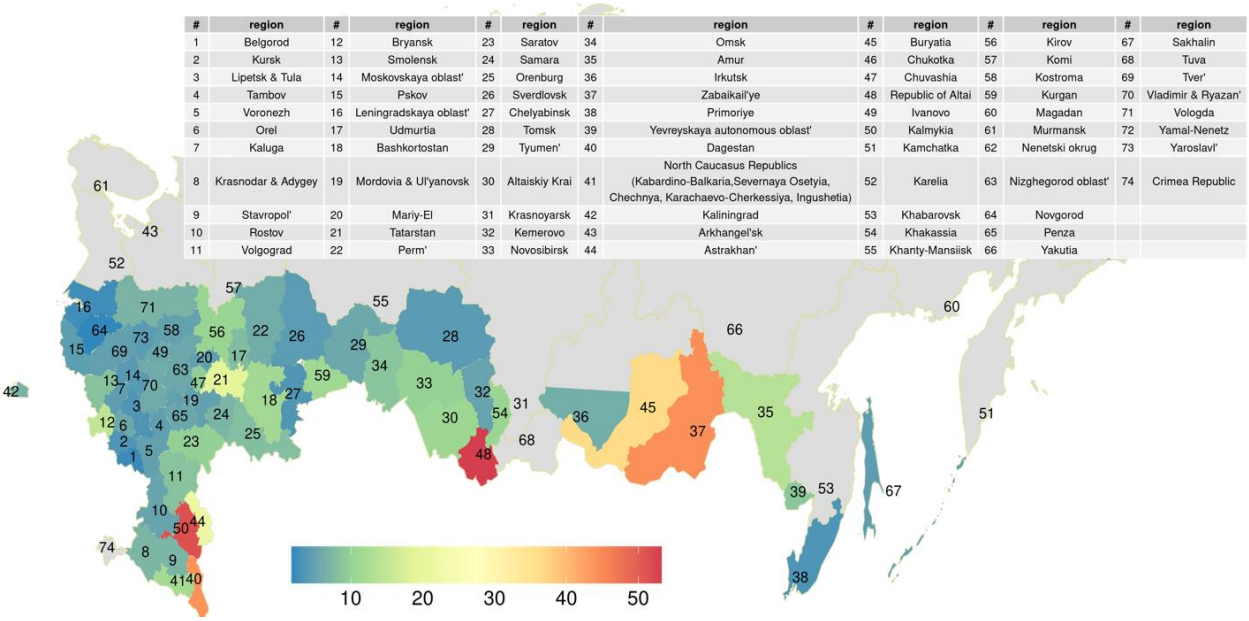
| 11 | Volgograd | 22 | Perm' | 33 | Novosibirsk | 44 | Astrakhan' | 55 | Khanty-Mansiisk | 66 | Yakutia | | |

Source: authors estimates with GLOBIOM

Figure S19. Livestock GHG emission intensity in 2030 in intensive scenario, ton CO2eq / ton livestock protein




| # | region | # | region | # | region | # | region | # | region | # | region | # | region |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Belgorod | 12 | Bryansk | 23 | Saratov | 34 | Omsk | 45 | Buryatia | 56 | Kirov | 67 | Sakhalin |
| 2 | Kursk | 13 | Smolensk | 24 | Samara | 35 | Amur | 46 | Chukotka | 57 | Komi | 68 | Tuva |
| 3 | Lipetsk & Tula | 14 | Moskovskaya oblast' | 25 | Orenburg | 36 | Irkutsk | 47 | Chuvashia | 58 | Kostroma | 69 | Tver' |
| 4 | Tambov | 15 | Pskov | 26 | Sverdlovsk | 37 | Zabaikail'ye | 48 | Republic of Altai | 59 | Kurgan | 70 | Vladimir & Ryazan' |
| 5 | Voronezh | 16 | Leningradskaya oblast' | 27 | Chelyabinsk | 38 | Primoriye | 49 | Ivanovo | 60 | Magadan | 71 | Vologda |
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Source: authors estimates with GLOBIOM