China's pig relocation in balance

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China's pig relocation: do the losses outweigh the gains?

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The human population is unevenly distributed across the world, and so are livestock numbers (*1*). Within many countries, there is a significant correlation between the densities of humans and livestock, because the latter tend to be concentrated in the vicinity of markets. However, these two populations do not 'cohabit' easily at very high densities, especially in affluent regions. As a result, livestock production is increasingly expelled from urban areas because of unpleasant odors, air and water pollution, and/or the risks of zoonosis (*2*). Livestock farms in regions of high human population often have to implement a range of costly technological measures to decrease the odor burden, the emissions of potential pollutants to air and water, and the risks of disease and pathogen transfer. The competiveness of peri-urban farms may decrease due to implementation of these costly measures, and farms may be transferred to other less-populated or un-polluted regions.

China has shown a trend similar to that described above, but there are also formal 'no-go' areas for livestock farms. In May 2015, the Chinese government released an

Action Plan for Prevention and Control of Water Pollution (http://www.gov.cn/zhengce/content/2015-04/16/content_9613.htm). An important measure of this action plan is the establishment of non-livestock production regions (NLPRs) near vulnerable water bodies. The main aim of the NLPRs policy is to reduce the serious water pollution caused by livestock production in China, where 30-60% of watercourses have been severely contaminated, with livestock production being the dominant contributor (*3*). The NLPRs policy was implemented within 2.5 years of inception, and by the end of 2017 90,000 NLPRs had already been established. The total area of NLPRs is around 0.82 million km^2 in 2017. The NLPRs has forced 0.26 million pig farms to shut down (*4*). The closure of these farms has decreased the number of slaughtered pigs by 46 million head per year between 2014 and 2017 (Fig S1-2), which is almost equivalent to the total pig production in Germany or Spain, the 3rd and 4th world pig producers. China's NLPRs policy is unprecedented in the world in terms of the geographical area and number of farms affected, and its speed of implementation.

The consumption of pork in China is forecast to increase by 50% between 2010 and 2050, and the number of pigs is predicted to increase from 680 to 100 million head $year^{-1}$ (*5*). This will need a transformative relocation of pig production in China. Hence, it is important to address the question 'Which farms and regions will take over the market share in the future?' The Chinese government has assigned relatively poor provinces in the north and west as future development regions for pig production (Fig

S2). The main rationale for selecting these provinces is the current relatively low pig population density, and the relatively large land availability for application of pig manure (Fig 1a, b). This means that because of the current concerns of water quality, most of the additional pig demand (to 2050, i.e. 320 million head, representing 20% of global pig production) which was originally produced in southern regions of China will need to be met by production systems in the northern regions, However, a pollution burden will also be transferred to the new regions, some of which already have large areas of fragile natural grasslands and forests (Fig 2a, S3), while others already face serious pollution problems from industry and intensive vegetable and crop production. These northern regions of China are already suffering from e.g., high nitrate concentrations in groundwater (Fig 1c) and high ammonia emissions to air, due to intensive crop and livestock production (Fig 1d).

Pollution swapping through NLPRs and pig relocation policies

The NLPR and pig relocation policies seem very effective at first glance, as pollution sources are removed from current vulnerable areas, and economically less developed regions will receive new enterprises and job opportunities, as well as government subsidies to promote local economy. The NLPRs policy requires that all livestock farms be closed or moved away from NLPRs. Evidently, this will have positive impacts on water quality. It is estimated that nutrient losses to water courses from livestock production systems may decrease by up to 27% for nitrogen (N) and up to 48% for phosphorus (P) in southern provinces (*6*). Southern provinces will benefit most because they have the largest area of NLPRs and the highest livestock density (Fig S2).

Under the pig relocation policy, newly constructed pig farms in the developing northern regions are required to have enough manure storage and processing facilities to facilitate efficient utilization of manure nutrients. However, it appears that there is a lack of appropriate technologies, investment capital and willingness to implement these regulations in the new development regions. Only 20% of the industrial livestock farms in the development regions have implemented such regulations, and direct discharge of manure into the wider environment is still common in these farms (7). In addition, most of the new industrial-scale livestock farms have simple manure/slurry lagoons where pollutants are emitted into the air (ammonia and methane) and/or seep into the soil, resulting in nitrate leaching to groundwater and surface waters (Fig 2b). Hence, the NLPRs and pig relocation policies have decreased surface water pollution in southern China but have increased groundwater contamination and air quality problems in the northern China (Fig 2c, d).

Environmental costs of pig production

We estimate that ammonia emissions will increase by 20 to 50% between 2015 and 2050 in the new potential pig development regions in the northern 4 provinces (Inner-Mongolia, Liaoning, Jilin and Heilongjiang) and the North China Plain (Henan, Hebei and Shandong), since the additional pig production will be concentrated in these provinces (Fig S3). Current ammonia emissions are already high in these regions (Fig 1d), and there is already public concern about air pollution, human health and biodiversity losses. In the European Union, the average human health cost and bio-diversity losses in nature caused by ammonia emission from pig production were estimated to range between 11-170 Euros per head of pig (*8*). There is no estimation of the environmental costs of pig production in China yet. We do not exclude the possibility that the costs of pig production for the environment and human health are as large as or larger than the economic profit of pig production in China, which was about 30 Euros per head of pig in 2010-2015 (*9*).

Impacts on the supply chain and equality

Relocating pig farms has effects on the entire pork production and supply chain. Due to the NLPRs, self-sufficiency of pork production has been reduced by 20-40% in Zhejiang, Shanghai and Guangdong province between 2014 and 2017 (Fig S4a). Around 40-50% of pork consumption in these provinces now relies on import from other provinces (Fig S4b). Chinese consumers prefer fresh meat to frozen meat, and long-distance (up to more than one thousand kilometers) transportation of live pigs has increased markedly. In 2017, 140 million pigs (20% of total annual pig production) were transported trans-regionally to meet the pork demand of different regions (Fig S5), a situation which will be exacerbated by the spatial relocation of production and concentration in few north provinces. This causes animal welfare problems and has increased the vulnerability of the production-consumption supply chain. For example, trans-regional transportation of pig and pork has been banned recently, due to the outbreak of African Swine Fever Virus throughout China.

Besides, the richer southern provinces have reduced their pig production *per capita* during the last decade, and increasingly rely on poorer north and west regions to fulfill their pork demand (Fig S6a, b). Previous studies have also shown an unequal exchange of goods and services from north to south, with a subsequent increase in the environmental burdens in northern and west provinces (*10*).

Sharing the benefits and burden of livestock production among regions

Evidently, there is an urgent need for proper spatial planning of livestock production between regions, taking into account all environmental aspects, to optimize production, to minimize the cost, and to share the benefits and burdens. This must be done with extreme caution, as follows from the lessons of China's NLPRs and pig production relocation policies, as pollution swapping looms and the losses could outweigh the gains. Spatial planning must be accompanied by the adoption of a series of pollution mitigation technologies. The identification of vulnerable zones must address multiple risks: environment (ammonia and greenhouse gas emissions, nitrate leaching, water use); soil degradation (soil erosion, nutrient accumulation, heavy metals); human health (particular matter formation, zoonosis, anti-microbial resistance); biodiversity loss and animal welfare. Livestock production in vulnerable regions must be restricted. Best practices for animal housing, animal feeding, manure collection, storage, treatment and use on crop land need to be implemented fully on all farms, especially in new livestock developing regions.

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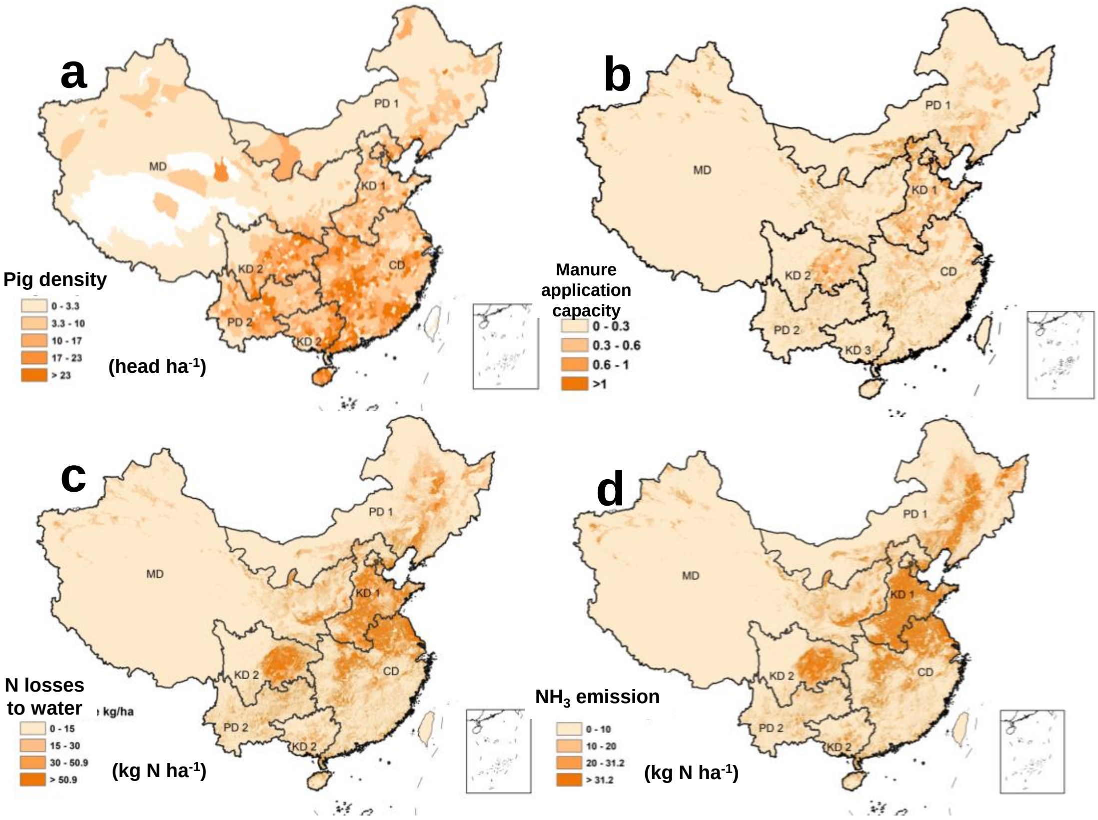

Fig 1. Maps of China showing for 2012 (a) the regional distribution of pig production (head of pig ha^{-1} agricultural), (b) capacity of manure application (expressed as the ratio of total manure nitrogen N produced and total nitrogen (N) uptake in harvested crop), (c) average N losses from agricultural land to water bodies, through leaching, runoff and erosion, kg N ha^{-1} agricultural land), and (d) average ammonia (NH_3) emission from agriculture (kg N ha^{-1} territory land).

Note: Results presented in Figures a, b, c, and d were calculated with the NUFER model (Wang et al., 2018). Letters on the map refer to different pig production development regions (Fig S1-2), where KD is key development region, PD is potential development region, MD is moderate development region and CD is constraint development region.

Fig 2.The contrasting natural biodiversity of grassland (a) and large manure ‘lake’ (b) in Inner Mongolia.