Full title

No milk without meat: Dynamic implications of the biological link between milk and bovine meat production on nutrition guidelines

Short title

No milk without meat

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Data availability statement

The data that support the findings of this study are openly available.

An interactive version of the model is freely available at https://exchange.iseesystems.com/public/birgit/no-milk-without-meat.

The model and a full technical documentation are available at https://github.com/bkopains/no-milk-without-meat/. The model and its documentation are also submitted as supplementary information. The model can be run with the isee Player https://www.iseesystems.com/softwares/player/iseeplayer.aspx.

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Abstract

The EAT–Lancet Commission report on healthy diets from sustainable food systems calls for a "great food transformation". This planetary-health-diet (PHD) ensures healthy intake levels across food groups and keeps environmental impacts within planetary boundaries, but operational nutrition recommendations for countries have yet to be determined. We argue that the biological link between milk and bovine meat production must be considered when operationalizing the PHD to national contexts. Using a stylized computer simulation model, we explore the impact of dietary scenarios on milk and bovine meat production. Results show that ignoring this biological link can lead to substantial imbalances between nutrition recommendations and production outcomes. A review of current national nutrition recommendations in Europe reveals that the vast majority of recommendations disregard the milk-bovine meat biological link and are not compatible with the PHD. This has implications for policymakers and consumers to consider when adapting the PHD to national contexts.

The EAT–Lancet Commission report on healthy diets from sustainable food systems calls for a "great food transformation" (Willett et al., 2019). This "planetary health diet" (PHD) ensures healthy intake levels across food groups, mitigates disease burdens, and keeps environmental impacts within planetary boundaries (Rockström et al., 2009; Steffen et al., 2015). On a global level, the diet suggests to double consumption of fruit, vegetables, nuts, and legumes, and to halve consumption of red meat and sugar (EAT, 2019; Willett, et al., 2019).

The PHD, derived from a global food systems model with country-level detail, is to be seen as a vision, and we acknowledge debates about its assumptions and calculation (e.g., Beal et al., 2023; Breidenassel et al., 2022). Yet, building on the vision of the PHD, countries need to review their nutrition recommendations and operationalize the PHD to national contexts. Current national nutrition recommendations primarily include health recommendations that only partly consider those formulated by the World Health Organization and largely lack sustainability assessments

(Herforth et al., 2019). For example, consuming 100 grams of protein from beef causes 50 kg, and 1000 grams of protein from milk causes 17 kg of CO_2-equivalents in emissions (Poore & Nemecek, 2018). This indicates a need to favor dairy-product over bovine meat consumption to reduce environmental impact. However, the biophysical feasibility of this is questionable as bovine meat and milk production are biologically linked: in high-income countries, dairy cows must birth one calf every year to maintain sufficient milk production. Currently, meat and milk production processes are roughly balanced, as dairy cows usually stay on lactation for five to six years, and one calf moves into the dairy cow stock every five or six years to replace older cows. The remaining four or five calves are raised for meat. This meat supply is complemented with meat from slaughtered suckler cows. The biological link between milk and meat production also persists if the number of lactations per dairy cow is increased or decreased in different milk production systems. The PHD considers this biological link, but some work on sustainable diets (e.g., Mazac et al., 2022) and many current national nutrition recommendations do not. The latter often misalign recommended dairy-product and bovine-meat consumption, like in the current Swiss dietary recommendations (Kopainsky et al., 2020).

Here, we focus on this biological link in dietary recommendations and assess the bovine meat and dairy-product consumption aspects of national nutrition recommendations in high-income countries. To do so, we, first, develop a computer simulation model that builds on existing research to explore the impact of dietary scenarios on milk and bovine meat production. We specify the model for a high-income country – Switzerland – and two dietary scenarios: the PHD and the Swiss national nutrition recommendations. We, further review European national nutrition recommendations for coherence regarding the milk–bovine meat biological link, and their compatibility with the PHD. We argue that this biological link must be considered when operationalizing the PHD to local contexts, and we provide implications for policymakers and consumers.

Results

Testing the impact of dietary changes on milk and bovine meat production

To test the impact of the proposed dietary changes on milk and bovine meat production in high-income countries with the example of Switzerland, we developed a stylized computational model (e.g., Struben et al., 2020; see online methods) comprising a simplified version of a food system model that explores the economic and environmental impacts of dietary changes in Switzerland (Kopainsky et al., 2020). The simplified model captures the dynamic interplay in the biological link between milk and bovine meat production (with dual-purpose breeds). Following the

PHD (Willett, et al., 2019), food demand is an input parameter and food production and environmental impacts are outputs.

We use the model to test national nutrition recommendations for two extreme scenarios, the Swiss Food Pyramid (SFP) and the PHD, for which we assume that the entire Swiss population follows nutrition recommendations starting in 2023. We compare scenario outcomes to current (“reference” in Figure 1) and indicated (“indicated”) production. We aggregate environmental impacts by calculating annual CO_2-equivalent emissions from the production of milk and bovine meat (FAOSTAT). “Indicated production” refers to milk and bovine meat production to satisfy demand. In the “SFP” scenario, we simulate the impact on production when the population follows Swiss Society for Nutrition recommendations, assuming an almost 50% decrease in bovine meat consumption versus 2022, and a 13% reduction in per-capita consumption of milk (Kopainsky, et al., 2020). In the “PHD” scenario, the Swiss population follows the PHD without relying on trade (i.e., no imports of feed or final animal products) and consumes 16 grams of bovine meat (58% of the 2021 value) and 500 grams of raw milk equivalents (57% of the 2021 value) per person per day. For both scenarios, milk consumption changes stimulate the adjusted milk cow stock through calves allocated to the breeder stock; changes in bovine meat consumption lead to adjusted average feeder cattle fattening time.

Figure 1 illustrates milk and bovine meat production, and emissions of greenhouse gases (in CO_2-equivalents) until 2050 relative to reference. Milk production (Figures 1a, b) follows dietary changes in both scenarios and shows largely expected behavior, with new dynamic equilibria at 90% of the reference in the SFP and 66% in the PHD scenario—both close to the indicated values. The adjustment, however, is not instantaneous because of time lags in the production system. One would expect bovine meat production in both scenarios to decline similarly (Figures 1c, d). Yet, when milk consumption decreases, feeder calves are slaughtered earlier and more beef meat becomes available in the short term (indicated by spikes in Figures 1c, d).

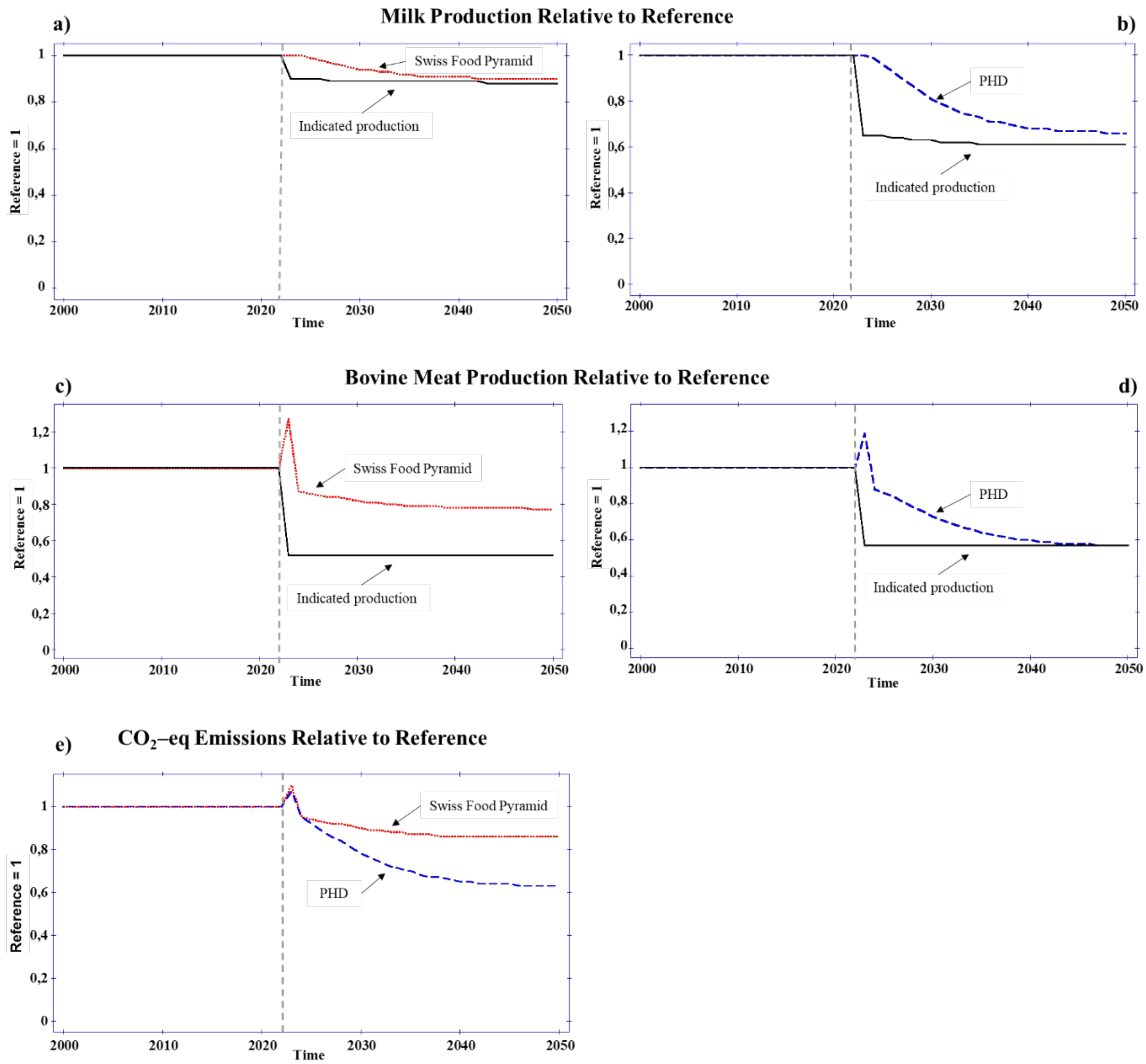

Figure 1: Impact of dietary change on milk and meat production and greenhouse gas (CO_2-equivalent) emissions, if the entire Swiss population follows dietary recommendations from 2023 (dashed vertical line). Panels a–d show indicated production relative to reference (solid line). ***Top panels:*** *Impact on milk production relative to reference from* ***a)*** *Swiss Food Pyramid (dotted line) and* ***b)*** *PHD (Planetary Health Diet) (dashed line).* ***Center panels****: Impact on bovine meat production relative to reference from* ***c)*** *Swiss Food Pyramid (dotted line) and* ***d)*** *PHD (dashed line).* ***Bottom panel: e)*** *Impact from milk and bovine meat production on CO_2-equivalent emissions relative to reference emissions: Swiss Food Pyramid (dotted line) and PHD (dashed line).*

In the SFP scenario (Figure 1c), bovine meat production slowly decreases after peaking and reaches a new equilibrium below the reference value at 77% of the reference—but roughly 1.5 times the indicated production at 52% of the reference. This is because as milk consumption decreases by 13%, and once the dairy cow stock is adjusted in response, the dairy supply line produces one calf per dairy cow per year, of which only every fifth calve is required to replace aging cows. The other four calves enter the feeder cattle stock to prevent milk overproduction. They are fattened for the minimum time required by law but nevertheless generate bovine meat—for which demand is low, per SFP recommendations.

In the PHD scenario (Figure 1d), bovine meat production, after the initial spike, decreases to a new equilibrium at around 57% of the reference, where it eventually meets indicated meat production per PHD recommendations. Here, bovine meat production follows the reduced consumption, again with a time lag.

In both scenarios, the environmental impact of food production and consumption declines versus the reference, following milk and bovine meat production. After the peak on introducing the new diets, CO_2-equivalent emissions from milk and bovine meat production decline to ~86% of the reference in the SFP scenario, and ~63% in the PHD scenario. The SFP scenario thus creates high unnecessary environmental impact and unnecessary inefficiencies in the production system.

A wider phenomenon? Current national nutrition recommendations in Europe

To assess whether our simulations are limited to Switzerland, we reviewed Food-Based Dietary Guidelines for milk and dairy products and for meat in 32 countries in Europe (European Commission, Tables 7 and 8; see supplementary materials) and analyzed whether (1) national milk and bovine meat nutrition recommendations correspond with the PHD and (2) the recommendations consider the milk–bovine meat link (Table 1).

<<Table 1 about here >>

Only Bulgaria's, Denmark's (FVM, 2021) and Malta's nutrition recommendations align with the PHD. Twenty-one countries' recommendations are misaligned, and seven provide insufficient data for analysis. Only six countries (Austria, Bulgaria, Denmark, Estonia, Malta, Netherlands) consider the milk–bovine meat link. The remainder either disregard it (mainly based on recommendations to eat white meat, fish, and vegetal substitutes versus bovine meat) or lack clear recommendations. Overall, national nutrition recommendations lean toward promoting white-meat and minimizing red-meat consumption while simultaneously recommending, on average, two to three portions of dairy per day. If fully adopted, these recommendations would cause similar imbalances between consumption and production as described in the SFP scenario.

Discussion

Policies should empower consumers to make informed food choices, thereby fueling demand for sustainable and healthy diets (Webb et al., 2020). This is particularly pressing in high-income-country contexts. Policymakers and consumers increasingly recognize that meat consumption must be reduced; however, they are unclear on which meat to reduce and/or how to replace it. Thus, consumers often replace meat with dairy versus plant-based options (European Commission, 2018). As illustrated in the SFP scenario, such consumption patterns require more dairy cows on lactation, causing an excess of calves born to the dairy stock and thus increased bovine meat production. Respecting links between food co-products like milk and meat is not only critical for the dairy food chain but for all food value chains in which such co-products are generated.

There are also trade-offs between increasing human health and reducing environmental impacts through diets. White meat is prioritized by many nutrition recommendations. The fewer greenhouse gasses emitted from white meat production versus red meat production (FAO, n/a) is valuable; however, the same recommendations often suggest maintaining current dairy-consumption levels, ignoring the milk–bovine meat production link and undermining intentions to decrease greenhouse gas emissions through reduced meat consumption. In addition, ruminants differ from other livestock in that their nutrition—in extensive grassland-based production systems—can avoid competition between crop production for animal feed and for direct human consumption (e.g., Schader et al., 2015). Feed-food competition would thus favor bovine meat production over white meat, chicken meat in particular.

Finally, there is a trade-off between meeting environmental goals and ethical standards for animal welfare. Replacing red meat with dairy products to decrease greenhouse gas emissions leaves excess calves. Regulations prevent slaughtering of excess male calves. Artificially increasing the proportion of female calves (e.g., Hayakawa et al., 2009) might reduce the share of male calves, but the problem of bovine meat oversupply remains.

Our analysis also entails limitations. The model's simplicity is important for analytical clarity. Additional detail could, for example, include explicit modeling of bovine meat production systems such as suckler cattle; however, this would reinforce the oversupply problem in scenarios such as the SFP. The suckler cattle system currently accounts for ~15% of bovine meat production in Switzerland (SBV, 2021) and can react more directly to changes in demand, but does not buffer milk–bovine meat demand imbalances. Moreover, we assume zero price elasticity—consumers simply adopt the recommended diet. In reality, excess bovine meat would cause price reductions, restimulating demand and exacerbating policy resistance.

Further, our model's aggregated nature prohibits differentiation between livestock production practices with their varying environmental impacts. Other animal breeds, different milk production systems, and/or varied climatic and topographic conditions do not affect the milk-meat link. However, the environmental impact of milk and bovine meat production would indeed change. Environmental impact varies substantially among producers of the same product (Poore & Nemecek, 2018), depending e.g., on agricultural practices around animal breeding, nutrition, housing, and manure management. The local context is thus less critical when it comes to the milk-meat link but particularly relevant when it comes to greenhouse gas emissions.

Still, environmental impact reductions from livestock production practices are limited, and even the lowest-impact animal products typically have greater impact than plant-based products (Poore & Nemecek, 2018). Milk and bovine meat production in Switzerland are examples of largely self-sufficient production systems, and we tested the PHD scenario without trade to focus on insights about the biophysical feasibility of nutrition recommendations. These points hold for most high-income countries and are likely even more pointed in countries less well-suited for ruminants than Switzerland. Finally, we did not investigate the potential of transitioning to plant-based alternatives for both milk and meat; the above issues can be alleviated by increased adoption of plant-based diets (Sun et al., 2022).

The biophysical feasibility of nutrition recommendations illustrates the need for operational understanding of the interlinked food production and consumption processes. It is difficult for food system actors to anticipate their dynamic implications including its time delays on production, health, and the environment. Further, implementation of such understanding requires coordinated and collective actions (Struben, et al., 2020) and interventions across policy domains, actors, and needs to overcome barriers. First, producers base their production decisions on incentives. Current incentives in high-income countries typically promote animal over plant production. New incentives aligned with the PHD thus require redesigned policy instruments (Willett, et al., 2019). Second, policy- and decision-makers responsible for designing these instruments must incorporate goals of different domains (e.g., agriculture, environment, health; Candel & Pereira, 2017). Thus, they must balance the interests of various actors. Finally, nutritionists need to become aware of the biological link and understand its dynamic consequences. They act as multipliers of nutrition recommendations towards consumers and thus are crucial to implement the PHD in society. Summarizing, even if actors understand the link, understanding its dynamic consequences across policy domains is crucial for good policy design and implementation of national nutrition recommendations aligned with the PHD.

References

Beal, T., Ortenzi, F., & Fanzo, J. (2023). Estimated micronutrient shortfalls of the EAT-Lancet planetary health diet. *The Lancet Planetary Health, 7*(3), e233-e237. doi: 10.1016/S2542-5196(23)00006-2

Breidenassel, C., Schäfer, A. C., Micka, M., Richter, M., Linseisen, J., Watzl, B., & (DGE), f. t. G. N. S. (2022). The Planetary Health Diet in contrast to the food-based dietary guidelines of the German Nutrition Society (DGE). A DGE statement. *Ernährungs Umschau, 69*(5), 56-72.

Candel, J. J. L., & Pereira, L. (2017). Towards integrated food policy: Main challenges and steps ahead. *Environmental Science & Policy, 73*, 89-92. doi: https://doi.org/10.1016/j.envsci.2017.04.010

EAT. (2019). Healthy Diets from Sustainable Food Systems. Food. Planet. Health. Summary report of the EAT-Lancet Commission: EAT.

European Commission. (2018). EU Agricultural Outlook for Markets and Income, 2018-2030. Brussels, Belgium: European Commission, DG Agriculture and Rural Development.

European Commission. (n/a). Food-Based Dietary Guidelines in Europe Retrieved 06.07.2021, from https://knowledge4policy.ec.europa.eu/health-promotion-knowledge-gateway/topic/food-based-dietary-guidelines-europe_en

FAO. (n/a). Global Livestock Environmental Assessment Model (GLEAM) Retrieved July 19, 2021, from www.fao.org/gleam/en/

FAOSTAT. Emission intensities Retrieved 09.03.2023, from https://www.fao.org/faostat/en/#data/EI

Hayakawa, H., Hirai, T., Takimoto, A., Ideta, A., & Aoyagi, Y. (2009). Superovulation and embryo transfer in Holstein cattle using sexed sperm. *Theriogenology, 71*(1), 68-73. doi: 10.1016/j.theriogenology.2008.09.016

Herforth, A., Arimond, M., Álvarez-Sánchez, C., Coates, J., Christianson, K., & Muehlhoff, E. (2019). A global review of food-based dietary guidelines. *Advances in Nutrition, 10*(4), 590-605. doi: 10.1093/advances/nmy130

Kopainsky, B., Frehner, A., & Müller, A. (2020). Sustainable and healthy diets: Synergies and trade-offs in Switzerland. *Systems Research and Behavioral Science, 37*(6), 908-927. doi: https://doi.org/10.1002/sres.2761

Mazac, R., Meinilä, J., Korkalo, L., Järviö, N., Jalava, M., & Tuomisto, H. L. (2022). Incorporation of novel foods in European diets can reduce global warming potential, water use and land use by over 80%. *Nature Food, 3*(4), 286-293. doi: 10.1038/s43016-022-00489-9

Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science, 360*(6392), 987-992. doi: 10.1126/science.aaq0216

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F. S., Lambin, E. F., . . . Foley, J. A. (2009). A safe operating space for humanity. *Nature, 461*(7263), 472-475.

SBV. (2021). Statistische Erhebungen und Schätzungen 2020 über Landwirtschaft und Ernährung. Brugg, Switzerland: Schweizerischer Bauernverband (SBV).

Schader, C., Muller, A., Scialabba, N. E.-H., Hecht, J., Isensee, A., Erb, K.-H., . . . Niggli, U. (2015). Impacts of feeding less food-competing feedstuffs to livestock on global food system sustainability. *Journal of The Royal Society Interface, 12*(113). doi: 10.1098/rsif.2015.0891

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., . . . Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science, 347*(6223), 1259855. doi: 10.1126/science.1259855

Struben, J., Lee, B. H., & Bingham, C. B. (2020). Collective action problems and resource allocation during market formation. *Strategy Science, 5*(3), 245-270. doi: 10.1287/stsc.2020.0105

Sun, Z., Scherer, L., Tukker, A., Spawn-Lee, S. A., Bruckner, M., Gibbs, H. K., & Behrens, P. (2022). Dietary change in high-income nations alone can lead to substantial double climate dividend. *Nature Food, 3*(1), 29-37. doi: 10.1038/s43016-021-00431-5

Webb, P., Benton, T. G., Beddington, J., Flynn, D., Kelly, N. M., & Thomas, S. M. (2020). The urgency of food system transformation is now irrefutable. *Nature Food, 1*(10), 584-585. doi: 10.1038/s43016-020-00161-0

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., . . . Murray, C. J. L. (2019). Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *The Lancet*. doi: 10.1016/S0140-6736(18)31788-4

Table 1: Compatibility of national nutrition recommendations with the planetary health diet (PHD) and with the milk–bovine meat production biological link. To assess compliance with the PHD, we followed Sun, et al. (2022) value of 7 (range 0–28) grams of bovine meat/person/day, and one portion—i.e., 250 (range 0–500) grams—of milk or milk equivalents/person/day.. To assess consideration of the biological link, we used Sun et al.'s (2022) daily bovine meat–milk consumption ratio of 0.03.

	Quantitative recommendations available for consumption of…		**Recommendations in line with PHD**			**Recommendations considering milk–bovine meat production biological link**	
	Dairy	**Meat**	**Confirmed**	**No specific recommendations provided**	**Not in line**	**Confirmed**	**Unclear, due to lack of transparent recommendations**
Austria	✓	✓			✓	✓	
Belgium-Flanders				✓			✓
Belgium-Wallonia	✓	✓			✓		✓
Bulgaria	✓	✓	✓			✓	
Croatia	✓	✓			✓		✓
Cyprus	✓	✓			✓		✓
Czechia				✓			✓
Denmark	✓		✓			✓	
Estonia	✓	✓			✓	✓	
Finland	✓	✓			✓		✓
France	✓	✓			✓		✓
Germany	✓	✓			✓		✓
Greece	✓	✓			✓		✓
Hungary	✓	✓		✓			✓
Iceland	✓	✓			✓		✓
Ireland	✓	✓			✓		✓
Italy	✓	✓			✓		✓
Latvia	✓	✓			✓		✓
Lithuania	✓	✓			✓		✓
Luxembourg	✓	✓			✓		✓
Malta	✓	✓	✓			✓	
Netherlands	✓	✓			✓	✓	
Norway		✓		✓			✓
Poland	✓	✓			✓		✓
Portugal	✓	✓			✓		✓
Romania	✓	✓			✓		✓
Slovenia	✓	✓			✓		✓
Slovakia	✓	✓			✓		✓
Spain				✓			✓
Sweden		✓		✓			✓
Switzerland	✓	✓			✓		✓
UK		✓		✓			✓