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Future consequences of climate change for EU pig production – A review

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Abstract

Climate change is already a reality for livestock production. In contrast to the ruminants species little is known about the impacts and the vulnerability of pig UE sector to climate warming. This review deals with the potential and the already measurable effects of climate change in pig production. Based on evidences published in the literature, climate change may reduce UE pig productivity by indirectly reducing the availability of crops usually used in pig feeding, spreading the vector or pathogen to new locations and increasing the risk of exposure to cereals contaminated with mycotoxins; and directly mainly by inducing heat stress and increasing the animal’s susceptibility to various diseases. Provision of realistic projections of possible impacts of future climate changes on EU pig sector is a prerequisite to evaluate its vulnerability and propose effective adaptation strategies. Simulation modeling approach is the most commonly used approach for exploring the effects of medium or long-term climate change/variability in pig production. One of the main challenge for this modelling approach is to account for both direct and indirect possible effects but also to uncertainties in parameter values that substantially increase the uncertainty estimates for model projections. The last part of the paper focus on the main issues that still need to be overcome for developing a decision support tools for simulating the direct and indirect effect of climate change in pig farms.

Keywords

Climate change; Heat stress; Feeding resources; Health; Modelling; Pigs.

Implication

In the future, modeling approaches have to be developed to correctly evaluate the consequences of the future climate in EU pig sector. Considering the current state of modeling work, addressing of both direct and indirect effects of climate change in a same meta-model remains a major challenge for research. Future assessments of the degree of vulnerability of EU pig sector to climate change may also consider different socio-economic contexts for improving their reliability.

Introduction

Pig production is a major contributor to the agricultural economy in Europe (EU). In 2018, the pig meat sector contributed 9% of total EU agricultural output and 35% of total EU meat output (source : https://ec.europa.eu/eurostat/fr/) The EU is the world's second biggest producer of pork after China and the biggest exporter of pork and pork products. In future, a major challenge facing the EU pig production sector will be to reduce its negative local and global impacts on the environment and satisfy animal welfare needs while at the same time maintaining the sector's profitability at a time of significant uncertainty as to the direct and indirect consequences of global warming.

Compared with ruminant species, monogastrics have received far less attention where the impacts of climate change are concerned (Escarcha et al., 2018; Mikovits et al., 2019). This is probably because ruminant animals are considered to be more vulnerable because they are immediately impacted by outdoor climatic conditions (whether directly or indirectly) whereas most monogastric animals reared in the mid-latitudes are housed in closed buildings where the temperature is, in theory well controlled. In the EU, housing for pigs is predominantly equipped with only mechanical ventilation systems, having no dedicated air treatment devices to provide heat relief (Vitt et al., 2017). Because high ventilation rates alone are insufficient for the removal of sensible heat from animals during the summer months, indoor air temperatures frequently exceed the upper limit of the thermoneutral zone with detrimental effects on animal performance. This problem is exacerbated during summer heat waves and in animals at certain physiological stages such as lactating sows and finishing pigs.

This paper aims to review the available knowledge of climate change impacts on EU pig production and to identify the main issues that need to be overcome to improve assessment of quantitative evaluations of the vulnerability of pig farms to the consequences of global heating.

Pig production in Europe

The EU countries with the highest production of pig meat in 2020 were Germany (5.1 million tons) and Spain (5.0 million tons), followed by France (2.2 million tons); together, these three countries account for more than half of the EU's total production (Source Eurostat). Since the nineties, growth in UE pig production has occurred mainly in Germany and Spain (Figure 1). This trend is expected to continue in 2021, driven by strong pork production in Spain. Pig farming in the EU is particularly concentrated in certain regions: Scandinavia (mainly Denmark), the central EU (mainly Germany, Poland, the Netherlands, and Belgium), the western EU (mainly France), and the southern EU (mainly Spain and Italy). In these EU countries, pigs produced in conventional intensive systems account for approximately 90% of total slaughter pigs (Bonneau et al., 2011).

Predicted evolution of climate in the EU

The climate crisis will lead to a rise in the average overall temperature in the EU. Projections from the EURO-CORDEX initiative (https://cordex.org) suggest that temperatures across the EU land mass will continue to increase throughout this century at a higher rate than the global world average. Inland temperatures in some EU regions are projected to experience an additional increase of 1.4 to 4.2 °C under the RCP4.5 scenario and by 2.7 to 6.2 °C under the RCP8.5 scenario (for the period 2071-2100 as compared to 1971-2000) (Jacob et al., 2014). These authors project the highest level of warming to be across north-eastern Europe and Scandinavia in winter and southern Europe in summer. Projected extreme weather events such as summer heat waves are expected to have the greatest impacts in the area of livestock production. In the literature, several indices have been used to characterize heat waves, all of which are based on a certain period of consecutive days (3 to 5 days) of excessively warm weather conditions (i.e., average ambient temperature > summer 90-95th percentile). Historical analysis provides numerous examples of extreme heat events that inflicted serious damage on livestock production. In France, the frequency and the intensity of summer heat waves have dramatically increased in the period 1947 – 2019, with more than the half of heat waves occurring since 2000 (Figure 2). This trend seems set to continue in the near future, with all climate scenarios showing a doubling of the number of heat waves from 2021 to 2050 (Soubeyroux et al., 2016). For the EU, future projections for heat waves were recently obtained from a set of 14 regional climate models under the RCP8.5 future emission scenario (Cardell et al., 2020). These authors predict general increases in the frequency, duration and amplitude of heat weaves (i.e., the accumulated heat stress exceedance for all days under warm conditions in a given period; expressed in degrees-day) in all the major production basins for pigs (Figure 3). The South

Eastern EU will experience a strong increase of the number of warm days (+26%), with heat wave amplitudes of up to 194°C day during the summer period by 2071-2095.

Consequences of climate change for pig production

Heat stress effects

Pigs are homeothermic animals that have to maintain a relatively constant body core temperature over a wide range of climatic conditions. Heat stress results from an accumulation of energy in the body brought about by an imbalance between total heat production and heat loss. In the thermoneutral zone of temperture, hHeat production (HP) is classically divided in 3 components: (i) fasting HP, (ii) HP related to physical activity and (iii) HP related to feed intake and its digestive and metabolic utilization (known as the thermic effect of feed). For 60 kg BW growing pigs, these three components represent about 60, 15 and 25% of the total HP, respectively (Le Bellego et al., 1999). Fasting HP is a function of the chemical composition of the animal (involving the relative weights of metabolically active body compartments such as viscera and lean (van Milgen et al., 1998).The thermic effect of feed is mainly determined by feeding characteristics (feeding level and nutrient composition) and by animal related factors such as the animal’s ability to deposit lean tissue (Noblet et al., 1999). The higher HP in leaner animals probably accounts for the fact that genetic selection aimed at increasing the amount and efficiency of lean growth in pigs also produces animals with higher sensitivity to HS (Nienaber et al., 1997; Renaudeau et al., 2011). Heat can be lost from the body by two physical processes: sensible and latent heat loss. Sensible heat can be gained or lost by conduction, convection and radiation depending on the temperature gradient between the body surface of the animal and its surroundings. In pigs, latent heat is lost mainly through the evaporation of moisture from the respiratory tract that occurs while panting as pigs have few active sweat glands (Renaudeau et al., 2006). This limited ability to lose heat by evaporation explains why pigs are very vulnerable to high temperatures, especially when, as in most conventional housing systems, the animals cannot access to a wallow or a watering device.

Thermal HS can be classified in two major categories: “acute HS” and “chronic HS”. Chronic HS designates a high ambient temperature over a long period of time (days to weeks) which may in theory allow partial or total acclimatization to the environment. There are numerous physiological consequences of chronic HS and these have been extensively reviewed in the past (Baumgard and Rhoads, 2013). Above the upper limit of the thermoneutral zone, core body temperature begins to increase as a result of the animal’s inability to adequately dissipate the excess heat load. The concomitant decline in feed consumption is considered to be the main adaptation mechanism to limit metabolic HP. This limited nutrient intake results in reduced production performance, health and well-being if the adverse conditions persist (Nienaber et al., 1999). In lactating sows, reduced milk production as a direct effect of HS has also been documented in the literature (Messias de Bragança et al., 1998; Vilas Boas Ribeiro et al., 2018). The temperature threshold at which performance starts to decrease depends on the animal’s particular characteristics (genotype, physiological stage) but it is also determined by factors relating to the conditions in which the animal is raised (feed management, housing conditions and climatic factors other than ambient temperature) (Renaudeau et al., 2012). The metabolic and physiological adjustments that occur in the course of acclimatization to chronic HS may have long-term consequences for animal performance. For instance, it is now well established that chronic HS during the gestation period may change the ability of the resultant offspring to express their genetic potential (Johnson and Baumgard, 2018). In particular, prenatal heat stress alters the distribution of energy between lean and fat deposition, resulting in fatter carcasses at slaughter (Johnson et al., 2015; Serviento et al., 2020).

Acute HS designates a short period of abnormal ambient temperature as is observed during summer heat waves. The short-term effects of acute HS (i.e., during exposure to elevated temperature) are already well described in the literature. During the first 24-48 h exposure to HS, primary responses observed in pigs include a drop in feed intake and a sharp rise in heat loss via the cardiovascular adjustments that are made to increase peripheral vasodilation at the expense of the delivery of blood to the splenic tissues (Collin et al., 2001; Renaudeau et al., 2010). In contrast, the consequences of such thermoregulatory responses for an animal’s ability to recover once a summer heat wave is over have been studied only recently (Mayorga et al., 2018). The reduction in nutrient and oxygen supplies alters the intestinal morphology, leading to a possible impairment of nutrient absorption and inflammatory stress for at least the 3-6 d period following acute HS (Abuajamieh et al., 2018). The absence of compensatory feed intake observed during the recovery period could thus be associated with the HS impacts on the gastrointestinal tract mentioned above and could lead to retarded growth with possible economic consequences (Renaudeau, 2020).

Availability and quality of feed resources

In 2019, feed production for the pig sector represented about 30% of total animal compound feed produced in EU (FEFAC, 2020). Feed materials used in compound feeds are obtained from a wide variety of primary sources of EU origin (cereals, oilseeds, rapeseed and sunflower meals, coproducts) and from other ingredients particularly rich in protein (soybean meals) that must be imported from third countries (USA, Brazil, Argentina) (FEFAC, 2020). Where feed resources are concerned, the potential impacts of global warming on the pig industry would probably be brought about mainly by cumulative changes in yields and feed-food competition levels, but also to a lesser extent by reductions in the quality of raw materials for pig feed.

At a global scale, the various predictive models infer for the main part that climate change will continue to reduce the production of major crops. By the end of the century, without considering CO_2 fertilization, effective adaptation and genetic improvement, each degree-Celsius increase in the global mean temperature is predicted to reduce global yields of wheat by 6.0% and maize by 7.4% with wide variations according to geographical area (Zhao et al., 2017). In that study, the models showed a slight non-significant negative effect on soybean yield (-3.1%/°C). However, climate-driven impacts on crop production are shown to be variable both across crop types and geographically for individual crops. In France, cereal yields are also predicted to decline due to climate change under a wide range of climate models and emissions scenarios. However, due to the positive effect of climate change in some areas and the increased demand for cereals, some authors predict an increase in arable land used for crop production in France at the expense of permanent pasture or forest (De Cara et al., 2014; Lungarska and Chakir, 2018). Under the most rapid warming scenario (RCP8.5) and keeping growing areas constant, a 16% decline in winter wheat yield, a 20% decline in winter barley yield, and a 42% decline in spring barley yield are predicted by the end of the century (Gammans et al., 2017). In all studies, the simulations have difficulty in accurately accounting for uncertainties still to be documented, such as water availability for irrigation, changes in phenology and cropping calendars, the effects of increased CO_2 concentrations on plant growth, along with the potential impacts of pests, diseases and weeds and the increased frequency of extreme events (Tubiello et al., 2007). Extreme weather, especially, may increase the risks of multiple simultaneous crop failures within regions or globally. In 2018, the drought experienced in the Northern, Central and Eastern EU led to massive losses in crop yields which were only partially compensated by higher yields in the Southern EU as the result of favorable spring rainfall conditions (Beillouin et al., 2020). These extreme climatic episodes of 2018 were also associated with above-normal temperatures in North America and the Caspian Sea regions resulting in a deficit in global crop production and causing cereal prices to spike. More generally, growing evidence indicates that climate change will adversely influence agricultural crop yields and cause greater year-on-year variability. The increased variability of the climate and the occurrence of more frequent extreme climatic events is expected to lead to additional price increases for the most important agricultural crops – wheat, maize, and soybeans – that are used for livestock feeding (Nelson et al., 2009). A simulation study has suggested that ,under the predicted impacts of climate change, world crop price levels will increase twofold and world crop price volatility will increase fivefold between 2000 and 2080 (Tran et al., 2012). This increase in crop prices would be driven by the combined effects of the direct and indirect impacts of climate change on production yields but also by population and income growth and demand for biofuels (Nelson et al., 2009). Despite steady progress in increasing feed efficiency through a combination of improvements in feed management and genetic selection, feeding will continue to be the biggest cost factor in pig production in the future. By contrast, as reviewed by Rozegrant et al. (1999), the prices of food-feed crops are likely to increase at faster rates than the prices of pig meat from now to

2050. As a consequence, the predicted rising costs of crops is likely to be one of the main threats of climate change for pig producers.

The potential impacts of climate change on the composition of crops is now beginning to be well documented in the literature. From a meta-analysis, a systematic reduction in minerals and protein concentrations in response to elevated CO_2 has been reported, especially for C3 crops (Taub et al., 2008). For wheat, barley, and rice, the reduction in grain protein ranged from 10% to 15% when grown at elevated (540-958 ppm) CO_2. For soybean and legumes more generally, the reduction in protein content is projected to be much smaller (1 to 2%). In addition to the reduced crude protein content, possible changes in amino acid composition may occur in cereal crops (DaMatta et al., 2010). Finally, high temperatures, especially if coupled with drought, are often associated with the production of secondary compounds (tannins, phenols, and other anti-nutritional factors) that protect plants against abiotic stresses and can result in lower feed digestibility for monogastric animals. Due to their high consumption of cereals and their limited ability to transform mycotoxins into less toxic products (Ji et al., 2016), pigs are the animal species most severely affected by mycotoxins. Climate represents the key factor in driving fungal community structure and mycotoxin contamination levels pre- and post-harvest (Magan et al., 2011). Climate change related effects that bring forward wheat flowering and full maturation by 1–2 weeks in north western EU could increase deoxynivalenol (DON) contamination by up to a factor of three, with an estimated mean DON concentration in this future scenario that exceeds the EC limit of 1250 μg/kg (Van der Fels-Klerx et al., 2013). A model designed to predict future alfatoxin contamination in cereal grown in Europe has shown that a +2°C climate scenario would result in a significant increase in contamination in all corn growing areas, whereas the predicted impact on contamination in wheat would be negligible (Battilani et al., 2016). These possible changes in patterns of mycotoxin occurrence in feed crops as the result of climate change have to be taken into consideration in order to assess the impact of climate heating in the pig sector and are a matter of concern that may call for anticipatory measures to be taken.

Health

Infectious diseases are among the primary constraints on pig production, and the globalization of the pig industry has contributed to the emergence and spread of pathogens, driven in part by the frequent movement of pigs, feed, and pork products at local, national, and international scales (VanderWaal and Deen, 2018). Despite the importance of disease prevention for animal health and the stability and productivity of the global pig industry, there have been few projections of the development of swine pathogens under future climate change scenarios in Europe. It is assumed that a heating climate would affect pig health, either directly by causing death or modifying the ability to cope with pathogenic agent exposure, or indirectly by increasing the risk of exposure to sanitary threats. Variations in climatic factors influence the survival and development of pathogens, and affect the spatial distribution of vector-borne diseases (Lacetera, 2018).

Direct impacts include temperature related illness and death, and morbidity of livestock under severe heat stress (Gaughan et al., 2009). In the past 2 decades, the increased frequency and severity of heat waves has resulted in many deaths of livestock across the world. In 2003, Europe experienced thousands of heat-related deaths in pigs in the course of a summer heat wave where the average temperature was 3.5°C above normal during a 2-wk period. In pigs, the risk of an increased mortality rate is particularly high for heavy finishing pigs and lactating sows and their litters. For example, a higher incidence of sow mortality during the summer months has been reported, especially in the 2-4 days after farrowing (Chagnon et al., 1991). When the temperature in the farrowing unit exceeds 22°C at parturition, the risk of stillbirth increases due to the prolonged duration of farrowing and the associated risk of hypoxia for piglets (Vanderhaeghe et al., 2010). In addition, a higher risk of pig death has also been reported during transport and lairage at the slaughter house in the hot season (Vitali et al., 2014). Based on our knowledge of humans and rodents, it has been suggested that the etiology of heat stroke is related to multi-organ system failure (Leon and Helwig, 2010). The primary cardiovascular response to heat exposure is an increase in skin blood flow promoting heat loss to the environment. Increased skin blood flow is accompanied by a fall in splanchnic blood flow as a compensatory mechanism to maintain blood pressure. As observed in reproductive sows, this rapid change in blood flow distribution would explain a large proportion of deaths due to cardiac failure (D'Allaire et al., 1996). Moreover, a reduction in splanchnic blood flow can result in an ischemia likely to produce nitrosative and oxidative stress that causes intercellular junctions in the gut to become “leaky” (Lambert et al., 2002; Pearce et al., 2012). Bacteria and bacterial products that are normally contained in the gut lumen are then able to freely cross the tight junction protein barrier and enter systemic circulation (Pearce et al., 2013). In addition to local gut inflammation, a systemic inflammatory response to endotoxin leakage appears to be an important element of heat stroke syndrome (Leon and Helwig, 2010). As well as reducing intestinal integrity, acute HS has been shown to induce morphological damage in the gastro-intestinal tract (GIT) (Pearce et al., 2012; Johnson et al., 2016) with possible transitory effects on nutrient digestion and absorption. This damage in the GIT would explain why pigs are unable to increase their voluntary feed intake on the days following the end of a heat wave (Renaudeau, 2020).

A further theory to explain a possible link between high temperatures and health problems is that stressors such as HS may impair components of the immune system, thus enhancing an animal’s vulnerability to disease (Gaughan et al., 2009). In ruminants, it has been suggested that heat stress would disrupt the immune function by changing the balance between cell-mediated immunity and humoral immunity (Bagath et al., 2019). This disruption in immune response seems to occur independently of feeding levels and is generally explained by the activation of the HPA axis and an increase in peripheral levels of glucocorticoids that then suppresses the synthesis and release of cytokines (Salak-Johnson and McGlone, 2007). For pigs, the data on the interactions between heat stress and the immune function are conflicting. Morrow-Tesch et al. (1994) showed that immunosuppression under heat stress conditions (28 d at 33°C) depends on social status in group-housed growing pigs. Immune suppression was also observed in pigs that endured chronic HS lasting 21 d (Xiang-hong et al., 2011). However, it has also been reported that pigs previously exposed to a 7-d HS displayed improved capacity to limit the physiological problems caused by repeated administrations of LPS (Campos et al., 2019). Whatever the nature of the stressors, specific and non-specific physiological and cellular adaptation responses were elicited in the animals. In other words, it was suggested that non-specific mechanisms to counteract the effects of acute HS had also helped the animals to cope with an inflammatory problem.

Under HS conditions, factors related to feeding conditions can influence a pig’s health status. For instance, the reduced voluntary feed intake that occurs under heat stress conditions reduces levels of the energy, protein, minerals, vitamins and trace elements that can help the pig to cope with health challenges.

Global warming can affect animal health by increasing the frequency of exposure to existing or emerging diseases by creating conditions conducive to the development vectors and their host reservoirs, and to the survival of pathogenic agents. Although the potential problems associated with climate change are now becoming widely recognized, quantitative data on the distribution and numbers of many vector species within the EU are not available and the influence of climate change on the distribution of these vectors remains highly uncertain (Gale et al., 2010). In pigs, a number of reports indicate seasonal changes in disease occurrence. However, the results of these studies are conflicting. Through the abattoir monitoring of pig carcasses, Lee et al. (2020) showed that the prevalence of respiratory problems increased during summer and fell in winter. A higher Salmonella seroprevalence was found in pigs exposed to housing temperatures over 26°C than in those kept at thermoneutral temperatures (Hautekiet et al., 2008). In contrast, a study of the influenza herd-level prevalence in Midwestern pig farms showed a seasonal pattern of higher levels of influenza in the winter and spring months (Chamba Pardo et al., 2017).

Pigs are very sensitive to mycotoxins due to their high consumption of cereals. As stated above, climate change has the potential to increase the risks that mycotoxigenic fungi pose to feed safety for pigs. Even though the major mycotoxins (aflatoxins, trichothecenes, fumonisins, zearalenone) have different toxic effects, all target the immune system (Pierron et al., 2016). The toxic effects of mycotoxin include increased susceptibility to and severity of infectious diseases, but can also impair vaccination efficacy, so that risk of disease increases even in appropriately vaccinated flocks (Pierron et al., 2016).

Methodological issues for evaluating the vulnerability of pig production to climate change

Pig production systems will need to adapt as the climate continues to change. Adaptation strategies for coping with climatic disruptions of pig production are well documented. For example, the adoption of generic management and technological adaptation measures have been found to be effective in reducing the impact of chronic heat stress in pigs (Renaudeau et al., 2012; Cottrell et al., 2015; Mayorga et al., 2019). However, such adaptation strategies take little or no account of specific climate change impacts. Thus, the production of realistic projections of the possible impacts of future climate changes on the EU pig sector is a prerequisite for the evaluation of its vulnerabilities and the proposal of effective adaptation strategies. This goal sets scientists the challenge of having to take account in our simulations of all the impacts of climate change, both direct (climatic conditions) and indirect (availability of feed resources, health pressures), but also of the socio-economic context in which changes to the pig sector will occur.

First, the direct impacts of future climate change in pig production can be estimated by using predictive computer models based on existing knowledge concerning the “dose-response” relationships between climatic conditions and animal performance. However, the purpose of these models is to show what would occur under different climate scenarios rather than to predict what exactly is going to happen. For the predictions of future climate, climatologists are now able to offer a satisfactory model of the climatic consequences of future greenhouse gas emission. These large-scale global climate models can be downscaled to make climate predictions at finer temporal and spatial scales in order to explore the potential effects of climate change on livestock production. By linking these climate scenarios with animal performance models, we can estimate the impacts of future climate on pig farm performance. Animal modelling requires the inclusion of a corpus of mechanistic and/or empirical mathematical equations to represent the complexity of animal/farm responses to the various environmental changes that result from climate change. To incorporate the specific effects of heat stress on pigs, mechanistic equations (where mathematical equations are used to describe the mechanisms that underlie statistical relationships) have been used to produce heat balance models to predict the effects of heat stress on pig feed intake, heat production and growth (Turnpenny et al., 2000; Fialho et al., 2004). However, to date, since we do not have sufficient knowledge of some of the parameters of the heat balance model, the accuracy levels of such models in predicting heat loss and change in feed intake are very low. An alternative has been to use empirical equations (based on statistical relationships between variables) to predict the effects of heat stress on voluntary feed intake in pigs. These equations are generally easier to handle than mechanistic equations because they can be quite simply derived by fitting statistical functions to experimental data published in the literature or directly collected on commercial farms (Renaudeau et al., 2011; Dourmad et al., 2015; Fragomeni et al., 2016). Equations of the latter type have recently been introduced to a model by being coupled with bioclimatic and growth sub-models to simulate the effects of raised temperatures on growing-finishing pig performance and carcass composition (Brossard et al., 2019). In this model, pig performance is predicted from changes in voluntary feed intake related to climatic conditions but it does not take account of the direct effects of higher temperatures on pig metabolism and health. More generally, if we are to improve the accuracy of our simulations and/or implement a model that can inform us on the effects of climate change on the pig sector, further work needs to be done to quantify the effects of high ambient temperatures on reproductive performance (farrowing rate, litter size, etc..), on the heat-related mortality and morbidity risks for those key physiological stages with high susceptibility to overheating (e.g., reproductive sows, finishing pigs), on the direct effects of extreme temperatures on health, and on the trans-generational effects of *in-utero* heat stress on growth and reproductive performance. In addition, in light of the growing future impacts of summer heat waves, complementary studies need to be conducted to evaluate the short and long term effects of such extreme heat events on pig performance (Renaudeau, 2020).

As described in this review, the potential impacts of climate change on the pig sector are not limited to the effects of high ambient temperature on animal performance. Given that feed costs comprise around 60-70% of the total costs or production, efforts to maintain or to reduce feed costs must continue to be a major concern if the pig industry is to remain competitive. Future rises in the predicted costs of primary cereal crops associated with feed/food competition and climate-induced reductions in production yields will represent a threat for the pig sector as cereal grains (wheat, corn, barley) are the principal sources of energy in EU pig diets. In addition, growing societal and environmental concerns in the EU about imported soybean meal from Latin America are likely to result in improved import standards requiring certified sustainable soy and(or) the development of protein self-sufficiency within the EU which carries the potential risk of increasing protein costs for the EU pig industry (Boerema et al., 2016). Finally, it is anticipated that bioenergy demands will create competition for land and water resources and exacerbate the existing competition for land caused by increased demand for feed resources (Thornton, 2010). As a consequence, it can be assumed that increasing feed costs would probably have a much greater impact on pig farm profitability than the direct effects of heat stress.

This suggests that in simulating the impacts of climate change on the pig sector we must consider various scenarios to provide reliable projections of feed costs.

As previously stated, the potential effects of climate change on pig health are significant, ranging from direct effects such as heat related mortality or morbidity, to indirect effects such as those associated with ecological changes and the spread of certain pathogens and vectors, or the increased risk of mycotoxin contamination. In order to assess the impacts of climate change on pig production, one future challenge will be to include the risk of animal disease in our simulations. This is made harder by the fact that, according to a comprehensive survey including contributions from many researchers across Europe, modelling livestock health and pathogens in the context of climate is a very complex matter (Özkan et al., 2016). For example, not only does it require more effective modelling of the spread of pathogens and vectors under climate change, it is also dependent on an improvement in our understanding of the complex relationships between the environment, hosts and pathogens.

During the 1980s, the technical performance of pig farms showed great improvement thanks to a concomitant improvement of animal management and an intense selection drive for highly prolific sows and fast growing, lean animals with a high feed efficiency. According to the French National Pig Management database, between 1980 and 2015, the per annum number of pigs marketed per present sow, growth rates and gain:feed ratios from 30 to 115 kg that were recorded on farrow to finish commercial farms increased from 15.1 to 22.9 pigs/year, 595 to 815 g/d, and 0.28 to 0.39 kg/kg respectively. It can be expected that these technical performance will continue to increase in future, unless the evolution would be disrupted due to a higher priority given to animal welfare. As a consequence, it is very likely that animals raised on commercial farms in 2050 or 2100 will differ considerably from current animals, making them even more vulnerable to future heat stress, especially if no heat tolerance traits are incorporated into the genetic selection criteria for pigs. This suggests that the analysis on which simulations of the impact of our future climate are based must take account of continued improvements to pig genetic potential.

Finally, modelling studies to evaluate the impacts of climate on the EU pig sector will also have to take into consideration the full range of uncertainties in the socio-economic environment, such as future demand for pig meat, the evolution of EU policy to promote greener and more sustainable pig production and changes to EU regulations concerning animal welfare.

Conclusions

In the absence of any effective adaptation options, the EU pig sector will be vulnerable to climate change through reduced animal performance and higher production costs. The impacts will result from a combination of direct effects of heat stress on pig performance and health status and indirect effects on the availability of affordable feed resources and sanitary pressures due to changes in the spread of pathogens and vectors. Future modeling approaches must be developed that can correctly quantify the consequences of future climate change for the EU pig sector. This step is necessary to provide farmers with the basis for an informed perception of climate risks and to propose effective adaptation strategies. Given the current development level of modelling techniques, the successful combination of both direct and indirect effects of climate change in the same meta-model remains a major challenge for research. Future assessments of the degree of vulnerability of the EU pig sector to climate change could improve their reliability by taking into account a variety of possible socio-economic contexts.

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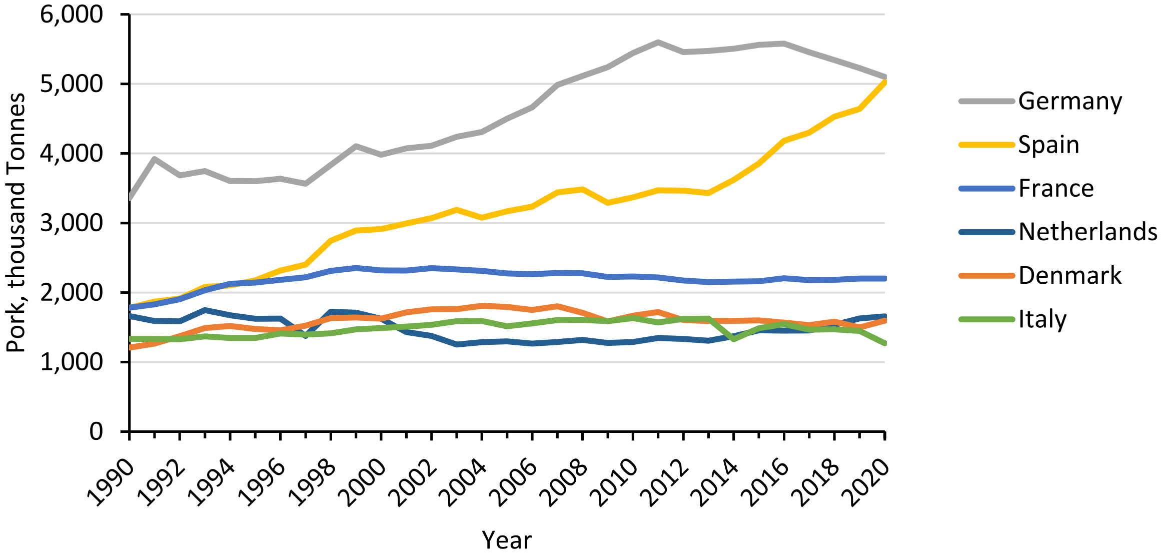

Figure 1 Evolution of pork production in the top six pork producing countries in the EU from 1990 to 2020 (source: own illustration based on the Eurostat database).

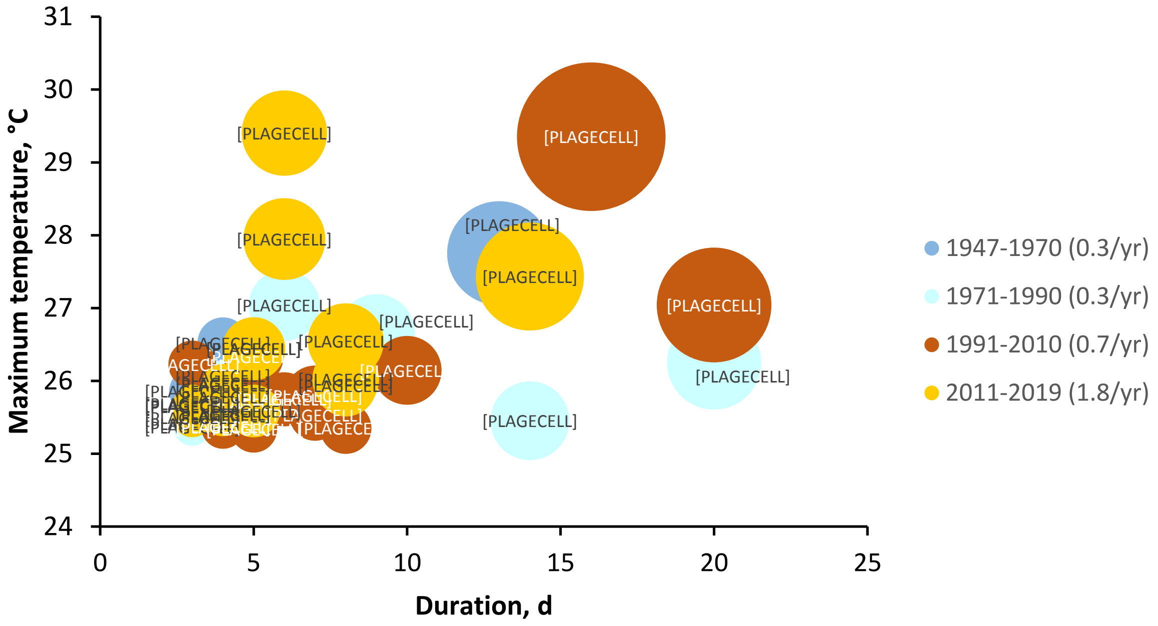

Figure 2 Heat waves recorded in France from 1947 to 2019. Each circle gives information on duration (x axis), maximum temperature (y axis) and global intensity (bubble size). Global intensity is an indicator of the severity of a heat wave. Data were provided by Météo France (J.M. Soubeyroux, personal communication). Details on the methodology used to characterize heat waves were provided by Ouzeau et al. (2016).

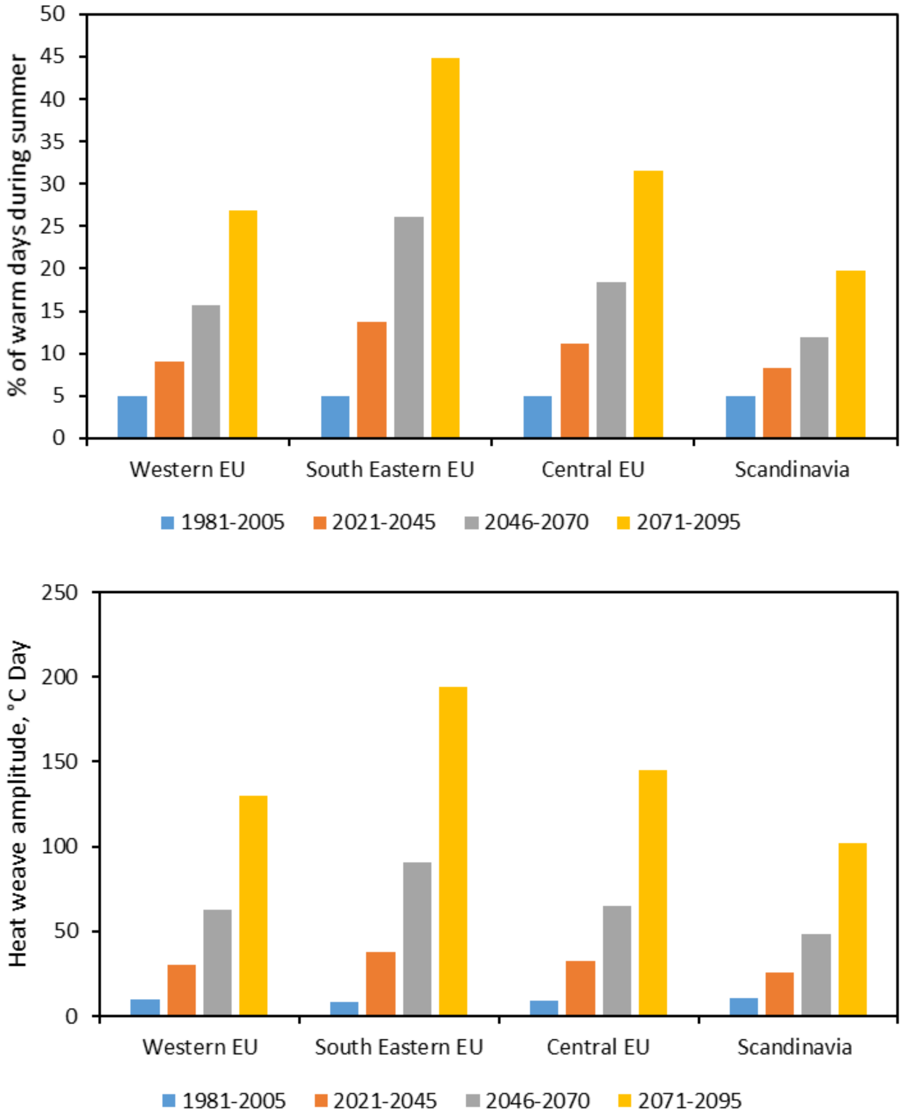

Figure 3 Multi-model amplitudes of regional summer heat waves (°C days) and percentage of warm summer days for the 4 EU regions comprising the main pig production basin, showing historic data for recent period (1981-2005) and projections for short term (2021-2045), medium term (2046-2070) and long term (2071-2095). Western EU = France, Southeastern EU = Spain, Scandinavia = Denmark, and Central EU =Belgium, Germany, Netherlands, and Poland. Adapted from Cardell et al (2020).