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Reducing energy consumption and greenhouse gas emissions from the European retail sector

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Winner of the 2022/2023 Ted Perry Award

Why you should attend:

1. To gain insights into how electrical carbon grid trends and strategic actions can help European supermarkets reach net-zero targets by 2050.
2. To understand how early adoption of innovative technologies leads to faster carbon reductions and greater long-term impact.
3. To learn how climate change will affect supermarkets across different European locations by 2050.

Abstract

The retail sector significantly contributes to global greenhouse gas (GHG) emissions, with refrigeration being a major energy consumer. This study investigates decarbonisation strategies for European supermarkets using an EnergyPlus modelling across six locations in France, Italy, Lithuania, Norway, Poland, and the UK. By incorporating projected climate data and electrical grid carbon intensities (EGCIs) from 2020 to 2050, the study evaluated impact on GHG emissions. Results show that electricity grid decarbonisation across all locations had the biggest effect on reducing emissions. Combining strategies, such as increasing store deadband temperature, installing doors on chilled cabinets, using air-source heat pumps (ASHPs), implementing 20% lower energy consumption cabinets and integrating solar panels, achieved carbon savings between 68.0% to 93.8%. Among individual strategies, solar panels proved most effective, particularly in high solar exposure regions. Climate change had a small impact on overall energy use. These findings offer insights for policymakers and retailers to support net-zero in the European retail sector.

Keywords: Retail, Greenhouse gas emissions, Refrigeration, Carbon neutrality, EnergyPlus, Sustainable practices

1. Introduction

The retail sector is a major contributor to global energy consumption and greenhouse gas (GHG) emissions, raising significant environmental concerns. Retail operations account for more than 25% of global GHG emissions [1]. Additionally, studies indicate that food and agriculture contribute to 26–35% of global emissions, with approximately 18–29% arising from the food supply chain [2,3]. Refrigeration plays a significant role in this footprint. Reports indicate that about 60% of food is refrigerated at some stage in the supply chain, and perishable foods are responsible for approximately 70% of GHG emissions within the food system [4].

Global warming further aggravates these challenges, with rising temperatures increasing the demand for cooling and refrigeration. The World Meteorological Organisation (WMO) has confirmed that 2024 was the warmest year on record, based on six international datasets. The past ten years (2015-2024) have all ranked among the ten warmest on record, highlighting an extraordinary streak of record-breaking temperatures. According to the WMO's consolidated assessment, the global average surface temperature in 2024 was 1.55 °C above the 1850–1900 baseline, with a margin of uncertainty of ± 0.13 °C. This likely marks the first full calendar year in which the global mean temperature exceeded 1.5 °C above pre-industrial levels [5]. Given these trends, there is an urgent need to develop and implement better solutions in the retail sector.

As part of the European Green Deal, the ENOUGH project (European food chain supply to reduce GHG emissions by 2050) was established to align with the EU's Farm-to-Fork strategy. This initiative aims to transform the European food sector into a more sustainable, resilient, and low-carbon system. A key focus of the project is reducing emissions in supermarkets, one of the most energy-intensive types of commercial buildings. The complexity of supermarkets arises from the interaction between external climate conditions, refrigeration systems, heating, ventilation and air-conditioning (HVAC) systems, lighting, and internal heat loads from equipment. These subsystems interact dynamically, with heat loads varying throughout the year. Therefore, understanding these interactions is crucial for optimising energy use and reducing emissions.

Several researchers have explored supermarket energy modelling and emissions reduction strategies [6,7,8,9,10,11,12,13]. For example, the authors of this paper developed an EnergyPlus simulation for a supermarket in Paris, evaluating interventions such as installing doors on refrigerated cabinets and using R-744 refrigerant while incorporating climate change projections to 2050 [14]. However, our focus was limited to specific interventions within a single climate zone. This research aims to expand on this work and evaluates the energy and carbon emission impacts of a medium-sized supermarket across six European countries: France, Italy, Lithuania, Norway, Poland and the UK. By incorporating projected electrical grid carbon intensity (EGCI) and climate data up to 2050, the study assesses the effectiveness of integrating different energy and carbon saving strategies. The selected locations represent diverse climatic conditions, various heating fuel sources and different EGCIs, making them ideal for evaluating different decarbonisation pathways. The findings from this study demonstrate the decarbonisation potential for supermarkets through to 2050, offering critical insights for policymakers, retailers, and industry stakeholders and contributing to the broader goal of achieving carbon neutrality in the European retail sector.

2. Materials and methods

The methodology used to develop the study was composed of three stages: identifying and reviewing strategies, modelling of supermarkets, and highlighting the decarbonisation potential of the retail sector.

2.1. Identification of strategies

As part of the ENOUGH project, 95 different technologies and strategies that retail stores could apply to reduce carbon emissions and energy consumption were reviewed and ranked [15]. Scope 1 and 2 emissions were covered which encompass emissions from direct fuel use (electricity/gas) and emissions from leakage of refrigerants. Scope 3 emissions were not included as these will originate from outside the retailers' boundaries. The reviews were used to identify the individual strategies that had the most potential in food retail stores. Only strategies with a high technology readiness level (TRL 8 or 9) were considered as carbon emissions options that were not on the market were very difficult to quantify and often had varied claimed savings.

Technologies with high TRL, high potential savings, and that were able to be modelled with EnergyPlus were then selected for this study. This included installing doors on open-fronted cabinets, adjusting the ambient store temperature dead band by 2 K, implementing air-source heat pumps (ASHP), improving refrigerated cabinets by 20%, and installing solar panels on supermarket rooftops.

2.2. Mathematical modelling

Mathematical modelling was then used to assess impacts from 2020 through to 2050 considering changes due to global warming and changes in the EGCI as well as the impact of combined strategies. EnergyPlus 2022 v22.2.0 simulation engine was used to calculate the total energy consumption for the modelled scenarios. SketchUp Pro 2022 (Trimble Inc.) was used to draw and create the model geometry. OpenStudio 2023 v1.5.0 (by NREL, ANL, LBNL, ORNL, and PNNL) was used as a graphical user interface to add and modify properties such as weather files, construction, materials, internal loads, schedules, water, HVAC, and refrigeration systems. The environmental impact was characterised by the total equivalent warming impact (TEWI).

The validated baseline supermarket model from Eid et al. [14] developed using EnergyPlus and located in Paris was then used for the other EU locations. The geometry for the 2,100 m^2 supermarket had 5 zones: sales, offices, dry storage, cold storage, and a machine room, with areas of 1,085 m^2, 111 m^2, 267 m^2, 526 m^2 and 111 m^2, respectively. The height of all zones was 6 m.

Table 1 only shows a subset of the model inputs for the supermarket, and further inputs for the baseline model, along with all necessary information, can be found in Eid et al. [14]. The documentation of the U.S. Department of Energy highlights all the equations used to calculate the loads across all modelled scenarios in EnergyPlus [16].

Table 1. A subset of the model inputs

Variables	Inputs		Source
HVAC system	Cooling DX Rated COP	3	EnergyPlus default
	Heating efficiency	1 (electric), 0.8 (gas)	Assumption
	Fan total efficiency	0.7	EnergyPlus default
	Heating thermostat	21°C Day - 19°C Night	Real store data
	Cooling thermostat	24°C	Real store data
Refrigeration system (R-744 booster)	Compressors	Bitzer-2GSL-3K-4SU (Low stage) Bitzer-4FTC-20K (High stage)	Assumption
	Evaporating T	Chilled/Frozen: -5/-30°C	[17]
	Defrost	1h/day (total) Chilled: Off cycle Frozen: 1400 W/m	Real store data
	Anti-sweat heater	None for chilled cabinets 100 W/m for frozen cabinets	Real store data
	Minimum condensing T	10°C	[18]
	Transition T	27°C	[18]
	Design T gas cooler	3 K greater than ambient T (transcritical) 10 K greater than ambient T (subcritical)	[18]
	Receiver pressure	40 barg	[18]
Display cabinets (all remote)	Case length	Chilled/Frozen: 83.75 m/18.7 m	Real store data
	Case height	1.5m	Real store data
	Operating T	Chilled/Frozen: 3°C /-18°C	EnergyPlus default
	Rated cooling capacity	Chilled: 1000 W/m (without doors) and 500 W/m (with doors) Frozen: 400 W/m	Assumption
	Fan power	30 W/m	Assumption
	Light power	20 W/m	Assumption
Cold chambers	Number	2 Chillers and 6 Freezers	Real store data
	Total area	Chillers/Freezers: 43 m^2/43 m^2	Real store data
	Operating T	Chillers/Freezers: 3°C/-18°C	Real store data
	Door height	2 m	Real store data
	Cooling coil capacity	4690 W	EnergyPlus default
	Fan	735 W	EnergyPlus default
	Light	120 W	EnergyPlus default
	Defrost	2500 W	EnergyPlus default

2.3. Locations and assumptions for baseline simulations

It was assumed that the baseline simulations across the 6 locations: France, Italy, Lithuania, Norway, Poland and the UK, were set for the year 2020. All simulations used an R-744 booster system and only differed in terms of heating fuel source (natural gas (NG), electric resistance, or ASHP) and weather files (specific to each city). All other elements remained the same in the simulations. Similar to the work of Eid et al. [14] for France and the UK, EnergyPlus weather files for the other locations were obtained from https://energyplus.net/weather. The selected cities for this study along with the fuel sources used for heating, the exact location of the weather files applied, and the average ambient temperature in each location are listed in Table 2.

Table 2. Differences in the baseline conditions across the 6 locations

	Heating fuel source	Weather file (city)	Ambient temperature (average)
France	Electric resistance	Paris (Orly)	11.1°C
Italy	NG	Rome	15.8°C
Lithuania	ASHP	Kaunas	6.8°C
Norway	ASHP	Oslo (Fornebu)	6.6°C
Poland	NG	Warsaw	8.3°C
UK	NG	London (Gatwick)	10.2°C

2.4. Climate change

The EnergyPlus weather files for the 6 locations were shifted to the period 2041-2060 period (termed 2050), considering historical climate change (https://weathershift.com/). The methodology for this process is detailed in Dickinson and Brannon [19]. The 2050 weather files employed representative concentration pathways (RCP) 4.5. According to the Intergovernmental Panel on Climate Change (IPCC), RCP 4.5 highlights moderate emissions peaking around 2040 and then decreasing. The objective was to examine how climate change affects the energy demand of the baseline supermarkets in the different locations. Figure 1 illustrates the monthly average ambient temperatures for 2050 under RCP 4.5 scenario across the 6 locations.

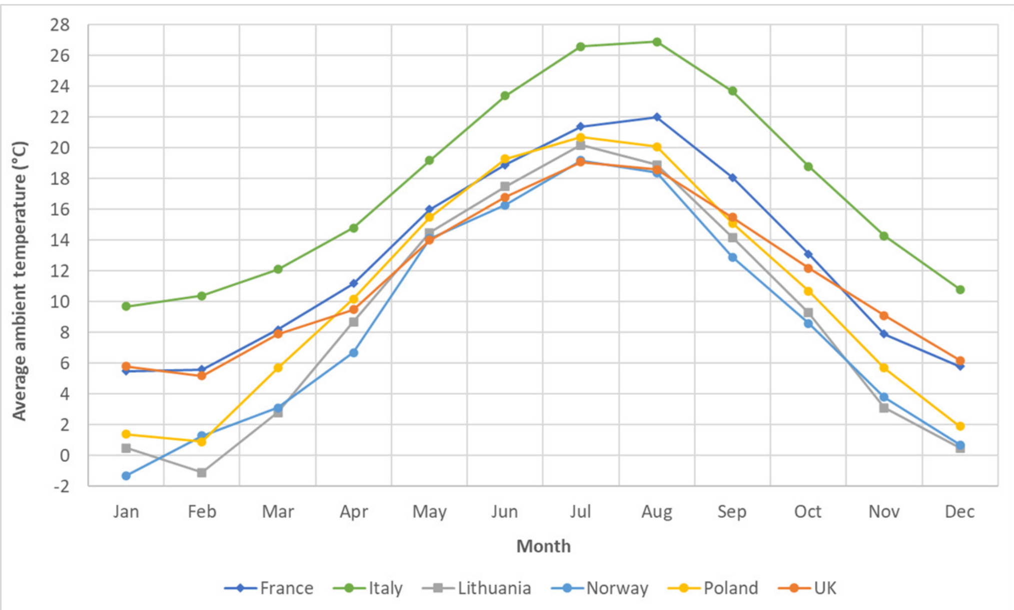

Figure 1. Monthly average ambient temperatures for 2050 under RCP 4.5 scenario across the 6 locations

2.5. Electrical grid decarbonisation

The study analysed the impact of the future EGCI between 2020 and 2050 for the 6 locations (where applicable). This was done to determine and demonstrate the decarbonisation potential of the baseline scenario (with no interventions) and the combined model where all the carbon-saving strategies were implemented together.

Figure 2 presents (where available) the changes to the EGCI in the 6 locations. Information on future EGCI was only available for 4 of the countries modelled (France, Lithuania, Poland (to 2040 only) and the UK). Therefore, for Poland, extrapolation was performed using three points (2030, 2035, and 2040), as Poland experienced rapid decarbonisation between 2020 and 2030, followed by a slower decarbonisation trend from 2030 to 2040. A quadratic polynomial curve (degree 2) was fitted to these points, and the extrapolated section is represented as a dashed line on the Poland curve. No information on future EGCIs was available for Italy and Norway. However, Norway already has the lowest EGCI among the six countries considered. Additionally, Italy has seen a decline in EGCI over the past 20 years, and if this trend continues, Italian supermarkets will likely become much lower carbon emitters by 2050 [20]. The EGCI for France was taken from Statista [21], for Lithuania from Lithuanian experts that calculated these based on official figures, for Poland from Statista [22], and for the UK from the UK BEIS [23]. The 2020 EGCIs for Italy and Norway were taken from EEA [24] and Equinor [25], respectively.

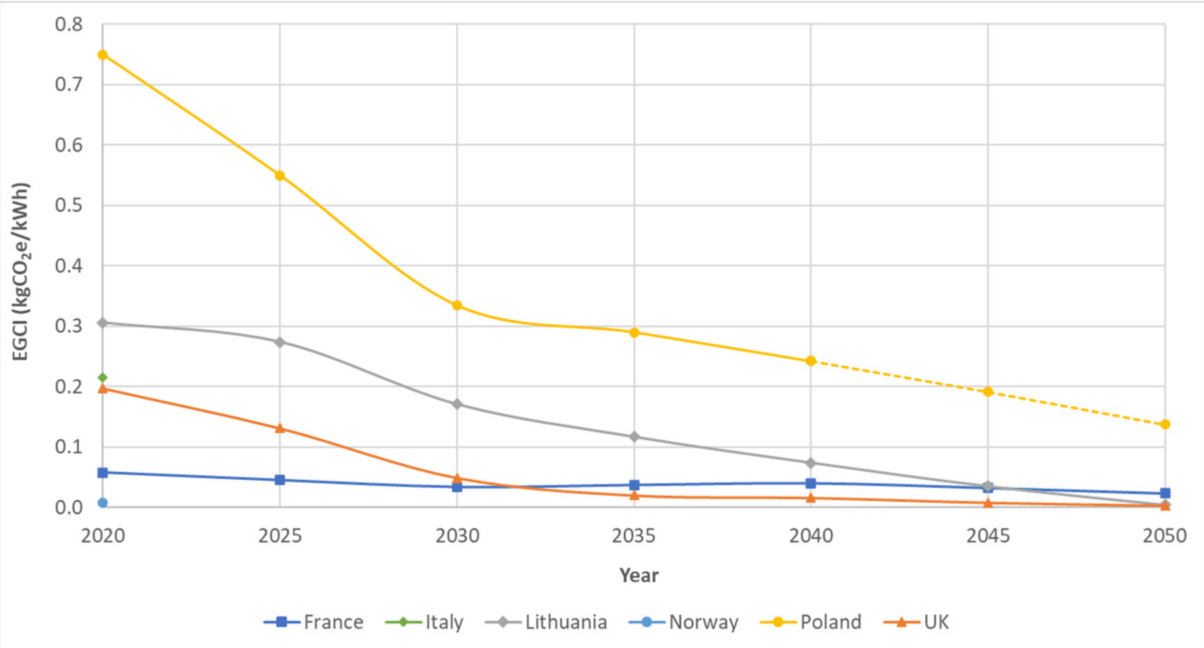

Figure 2. EGCI for the 6 locations studied

2.6 TEWI

The TEWI characterises CO_2e emissions and is a useful tool to study the impact of systems on global warming. The TEWI combines the direct and indirect emissions of CO_2e. TEWI is based on the following relation:

$$TEWI=(GWP\times m\times L)+(E_{gas}\times \beta_{gas})+(E_{electric}\times EGCI) \qquad \text{Eq. (1)}$$

Where TEWI is the mass of CO_2e produced during a year (kg); GWP is the global warming potential of the refrigerant ($GWP_{R-744} = 1$); m is the refrigerant charge of the store (kg), which was 380 kg [15]; L is the refrigerant leakage percentage per year (%/year), which was 10%; E_{gas} is the NG energy consumption per year of the store (kWh/year); β_{gas} is the CO_2e emission factor for the combustion of NG ($kgCO_2e/kWh$) which was 0.18 $kgCO_2e/kWh$ [26]. $E_{electric}$ is the electrical energy consumption per year of the store (kWh/year); EGCI is the CO_2e emissions per kWh of electrical energy produced ($kgCO_2e/kWh$). (GWP x m x L) and (E_{gas} x β_{gas}) represent direct CO_2e emissions from refrigerant leakage and NG combustion, respectively; ($E_{electric}$ x EGCI) are indirect emissions of CO_2e associated with electrical energy consumption.

2.7. Modelling strategies

Based on the technological reviews, the selected strategies applied for the 6 locations in this study were:

1. Strategy 1: Increase the dead band temperature of the HVAC by 2 K, by increasing cooling and decreasing heating set points by 1 K.
2. Strategy 2: Doors were added to the open fronted chilled cabinets.
3. Strategy 3: Change heating from gas or electric resistance to ASHP (for relevant scenarios) with a nominal coefficient of performance (COP) of 2.75.
4. Strategy 4: Refrigerated cabinets with 20% lower energy consumption (compressor, evaporator and condenser fans, defrost and anti-sweat heater, and case lighting) were applied for chillers and freezers.
5. Strategy 5: Solar photovoltaic (PV) panels were installed on the supermarket's roof. The electricity generated was calculated using the RETScreen v9.0 software tool. RETScreen uses published local data for daily solar radiation on a horizontal surface in $kWh/m^2/day$ for each month. The monthly output was calculated based on the fixed orientation of the PV panels, which were positioned at a 15° angle to the horizontal, their 6 different locations, and an assumed efficiency of 15%. The available energy from the solar panels was removed from the annual energy consumed by the store. It was therefore assumed that all solar energy generated could be used by the store (immediately or through energy storage).
6. Combined model: All the strategies above were combined in a single model to understand their potential impact on overall energy use and carbon emissions.

3. Results and discussion

3.1. Impact of climate change on the baseline supermarkets

This section shows the impact of climate change and the EGCI on the supermarket in the 6 locations.

Figure 3 show the impact of climatic temperature change on energy consumption for the 6 locations in 2020 and 2050. The graph presents information divided into heating, cooling (HVAC), lighting, interior equipment, fans, pumps, water systems and refrigeration. It is worth noting that space cooling was negligible because the supermarket had open-fronted chilled cabinets. As a result, the cold air from the cabinets naturally cooled the aisles, significantly reducing the need for cooling. Modelling showed that climate change had both positive and negative effects on energy use, depending on the location. It increased energy consumption in France, Poland and the UK but decreased it in Italy, Lithuania and Norway. However, despite these variations, the overall differences in energy consumption between 2020 and 2050 were small (less than 2%). The low impact of increasing climatic temperature was due to a balance between the heating and cooling demands on the supermarkets. As climatic temperatures increased, there was less energy demand for heating, but this was balanced by the increased energy demand for cooling and refrigeration.

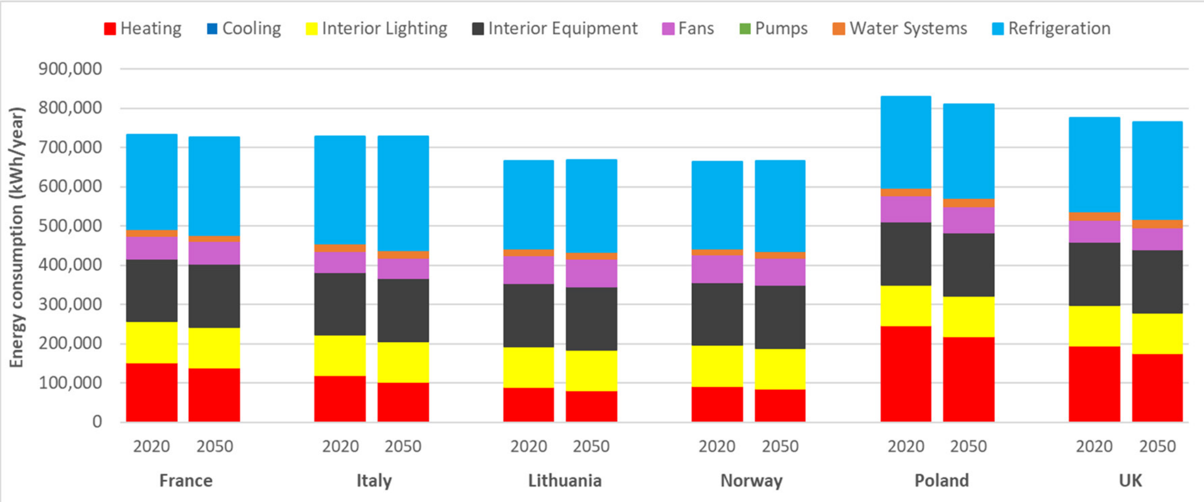

Figure 3. Impact of climatic temperature change on annual energy consumption of the supermarket between 2020 and 2050 in the 6 locations.

3.2. Impact of future EGCI changes on the baseline supermarkets

Figure 4 presents the total annual carbon emissions for the stores in each country. Over time, the EGCI is predicted to decrease considerably (as seen in Figure 2) and this had a major impact on the emissions from the stores. The store in Poland had the highest carbon emissions based on data up to 2050, reaching 126.1 tCO_2e/year, though the trend suggests a continued decline beyond this period. In London, despite the EGCI dropping to nearly zero (0.003 $kgCO_2e$/kWh) by 2050, the carbon emissions remained at 41.5 tCO_2e/year as the store was still heated by NG. In Paris, where electric resistance heating was used, emissions reached 17 tCO_2e/year by 2050 due to the EGCI of 0.023 $kgCO_2e$/kWh. In Lithuania, where heating was supplied by an ASHP, total emissions fell to nearly zero (2.7 tCO_2e/year) by 2050 due to the nearly zero EGCI (0.004 $kgCO_2e$/kWh). Although future EGCIs for both Norway and Italy were unavailable, emissions in Norway were already low in 2020 at 5.3 tCO_2e/year and are expected to be near zero by 2050, as an increase in the 2020 EGCI is unlikely, while Italy recorded 152.1 tCO_2e/year in 2020.

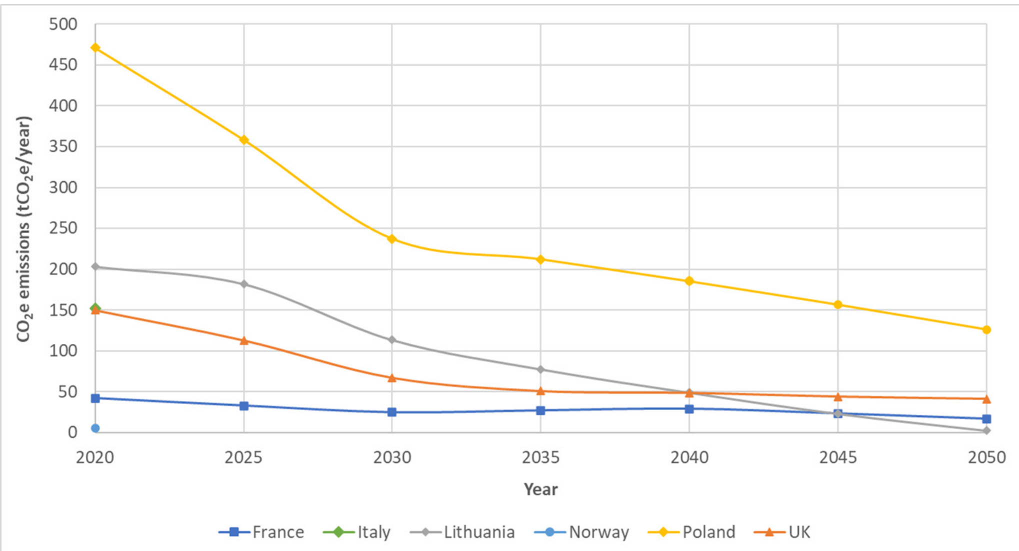

Figure 4. Impact of future EGCI changes on total carbon emitted by the supermarket in the 6 locations.

Although reaching carbon reduction targets at specified times is important, it is equally important, if not more, to consider the total carbon emitted over a period of time. By integrating the 4th order polynomial equations representing the CO_2e emission curves in Figure 4, the total carbon emissions from 2020 to 2050 were calculated for the baseline simulations. This resulted in accumulated emissions of 7,207 tCO_2e for Poland, 2,759 tCO_2e for Lithuania, 2,090 tCO_2e for the UK, and 835 tCO_2e for France. Poland had the highest accumulated emissions, while France had the lowest.

3.3. Impact of carbon reduction strategies

Each technology/strategy was applied individually and then in combination to the supermarkets across the 6 locations. The impact of the strategies applied on the energy consumption in 2020 is shown in Figure 5 and the impact of the strategies on carbon emissions is shown in Figure 6.

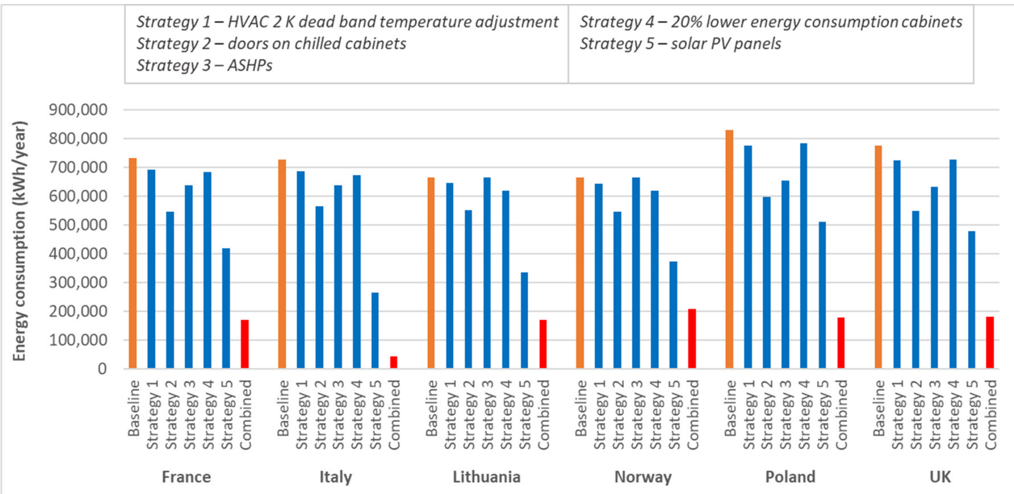

Figure 5. Impact on annual energy consumption of the different strategies applied individually and combined for the supermarket in the 6 locations in 2020.

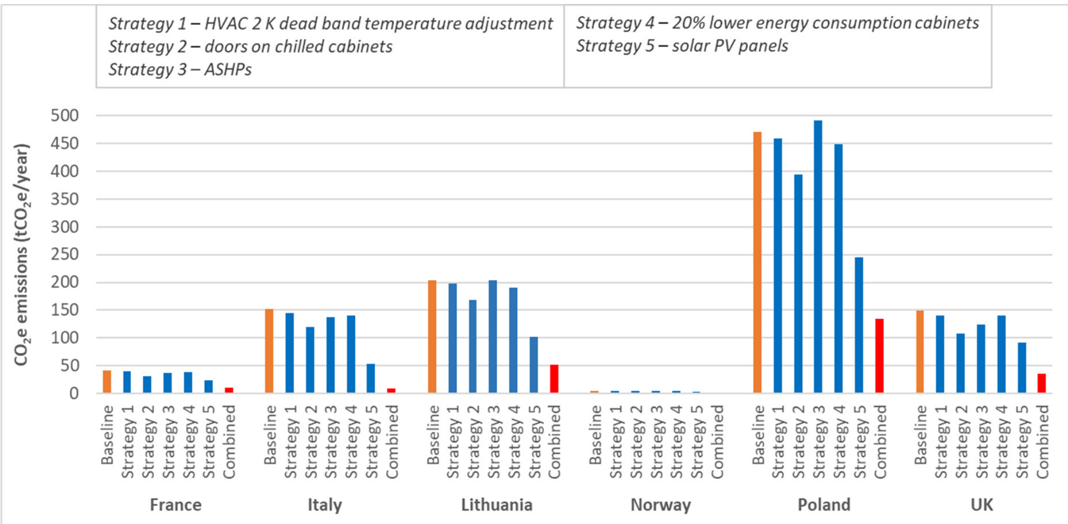

Figure 6. Impact on annual carbon emissions of the different strategies applied individually and combined for the supermarket in the 6 locations in 2020.

Strategy 1 (HVAC 2 K dead band temperature adjustment) resulted in relatively small percentage savings in energy across the 6 locations (between 3.0 to 6.5%). Energy savings were greater in countries that had either gas or electrical resistive heating (UK, France, Italy and Poland) and lowest in those that had ASHP (Norway and Lithuania). This was because of the efficiency of the ASHPs which had a COP of 2.75, versus electrical resistive heating with an efficiency of 1, and NG with an efficiency of 0.8. Reductions in carbon emissions (between 2.4 and 6.2%) again tended to be greatest in countries where NG or electric resistive heating was applied. The exception was Poland, and this was due to the high EGCI in Poland in 2020 (0.75 kg CO_2e/kWh). This meant that although strategy 1 was beneficial in energy, the benefits were less in terms of reducing carbon emissions as the EGCI was so much higher for electricity than gas. Due to the cabinets being remote and open-fronted, a large cooling load was provided for the store, making space cooling negligible. Therefore, the only benefit of this strategy was the heating component.

Strategy 2 (doors on chilled cabinets) saved between 18.0 and 29.3% of the overall store energy. This reduced the need for heating and refrigeration in the stores. The stores with ASHP (Lithuania and Norway) saw less reduction in energy than the stores which were heated using electrical resistive heating (France) or NG (Italy, Poland and the UK). This was due to the greater efficiency of the ASHP as described above. The greatest percentage reductions in carbon emissions ranging from 16.3 to 28.4% were observed in locations using NG or electrical resistance heating, except for Poland due to its previously discussed high EGCI.

Strategy 3 (ASHPs) led to energy reductions of 12.2 to 21.0% (where applicable). The impact of an ASHP was least significant in Rome, where the demand for heating was lower compared to other locations. The greatest energy savings were observed in Poland, as it was the coldest of the four locations where this strategy was applied, resulting in the highest heating consumption. ASHPs contributed to carbon emission reductions ranging from 4.3% to 16.8%. Despite the highest energy savings in Poland, ASHPs increased carbon emissions by the lowest amount (4.3%). This was because the increased efficiency of the ASHP COP did not overcome the higher EGCI (0.75 kgCO_2e/kWh) compared to NG (0.18 kgCO_2e/kWh).

Strategy 4 (20% lower energy consumption cabinets) achieved relatively small energy savings across all locations, ranging from 5.6% to 7.5%, with the lowest savings in Poland and the highest in Italy, as it had the highest refrigeration consumption due to it being the hottest location. Similarly, carbon emission reductions varied between 4.9% and 7.3%, with also the lowest reduction in Poland and the highest in Italy.

Strategy 5 (solar PV panels) resulted in energy savings ranging from 38.0% to 63.4%. Italy, with the highest solar exposure, achieved the highest energy savings, while Norway, with the least, had the lowest energy savings. This resulted in carbon emission reductions ranging from 38.6% to 64.7%.

The combination of all the previous strategies resulted in overall energy savings ranging from 68.6% to 94.0%. The highest savings were achieved in Italy, primarily due to the solar panels, while the lowest savings occurred in Norway, mainly due to solar panels having the least impact. In the other locations, energy savings were similar, ranging between 74.2% and 78.3%. Similarly, carbon emission reductions ranged from 68.0% to 93.8%, with Italy showing the greatest decrease.

3.4. Impact of future EGCI changes on supermarkets using the combined scenario

The impact of future EGCI on carbon emissions of the supermarkets across the 6 locations was assessed where all strategies were combined. As results showed that climate change had little effect on the supermarket's energy consumption in the 6 baseline scenarios, the 2020 energy consumptions, corresponding to the 2020 weather files, were used through to 2050 for emissions calculations. Figure 7 presents the impact of future EGCI on carbon emissions from 2020 to 2050 under this scenario. The significant reduction in EGCI over time greatly influenced the supermarket emissions. In the UK, emissions are projected to reach near zero (0.6 tCO_2e/year) by

2050, as heating will have transitioned from NG to ASHP. Similarly, in Lithuania, total emissions are expected to reach near zero by 2050 (0.7 tCO_2e). However, in France, total emissions did not fall as low in 2050 (4.03 tCO_2e) as the EGCI is still 0.02 $kgCO_2e/kWh$ and so higher than Lithuania and the UK. While Poland's carbon emissions were still the highest in 2050 (24.7 tCO_2e/year), the trajectory indicates that they will continue to decrease in the future.

By integrating the 4th order polynomial equations representing the CO_2e emission curves in Figure 7, the total carbon emissions from 2020 to 2050 were calculated. This integration resulted in accumulated emissions of 1,835 tCO_2e for Poland, 713 tCO_2e for Lithuania, 294 tCO_2e for the UK, and 196 tCO_2e for France. As in the baseline simulations (no strategies applied), France had the least carbon accumulated emissions, while Poland had the most.

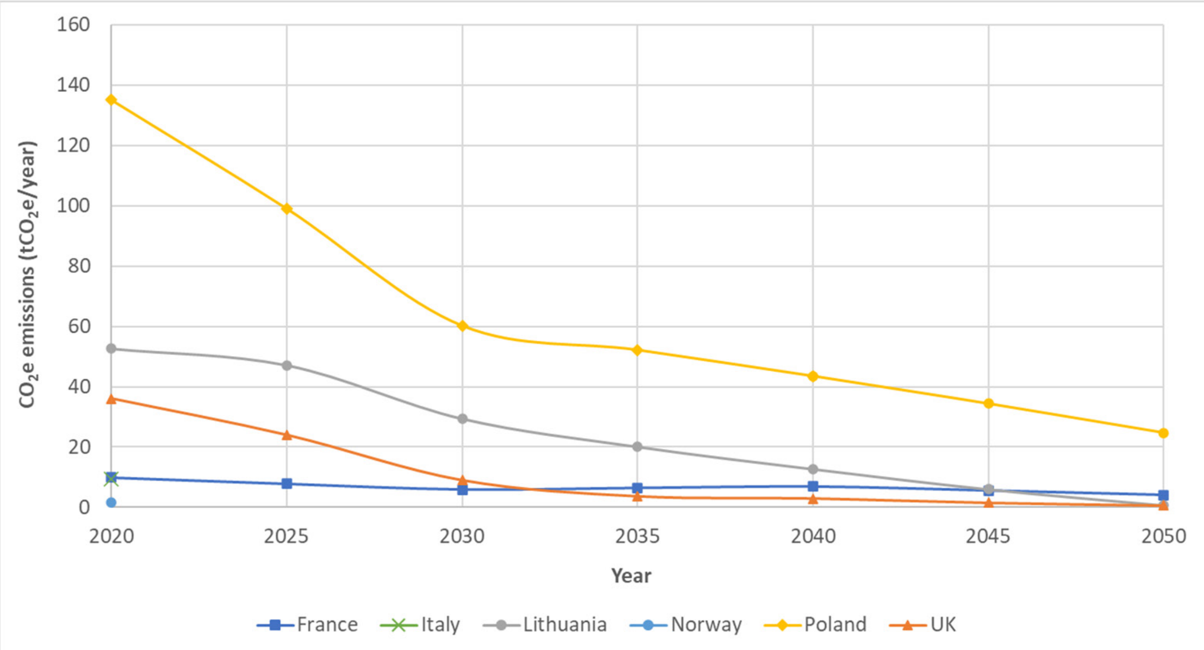

Figure 7. Impact on carbon emissions of the combined scenario for the supermarket in the 6 locations from 2020 to 2050

4. Conclusions

This paper examines how the European retail food sector can achieve rapid decarbonisation and reach near zero emissions. Using EnergyPlus modelling, the impact of various technologies and strategies across six locations were analysed from 2020 to 2050, considering factors such as global warming, and EGCI trends. The key findings were:

1. The decarbonisation of the electricity grid across all locations had the most significant impact on reducing the carbon emissions of the supermarket. This was even greater when fossil fuel-based heating was moved to electric.
2. The combination of technologies/strategies (increasing the deadband of the store by 2 K, adding doors to chilled cabinets, using ASHPs, implementing 20% lower energy consumption cabinets, and installing PV solar panels) resulted in carbon savings ranging from 68.0% to 93.8%, depending on the location.
3. The integration of solar PV panels was the most effective strategy, particularly in regions with higher solar

exposure, with carbon reductions between 38.6% and 64.7%.

4. Adding doors to chilled cabinets reduced energy use by 18.0-29.3% and carbon emissions by 16.3-28.4%.
5. HVAC cooling was negligible in this study (except when adding doors to chilled cabinets), as the supermarket used remote and open-fronted cabinets, which naturally cooled the space.
6. Climate change had a minimal effect on the overall energy use across the 6 locations, with less than 2% difference between 2020 and 2050, due to the balance between the heating and refrigeration demands.

As part of future research, we aim to use more complete EGCI data up to 2050. For solar PV panel calculations, future studies will model hourly energy generated and match it with hourly demand to consider if consumption is ever greater than demand. Additionally, different supermarket archetypes, including varying cabinet types (such as integral cabinets), will be examined to better understand their impact on energy consumption and carbon emissions. In addition, weather files that better predict maximum temperatures will be used. Projections under RCP 8.5 scenario will also be analysed to better assess potential climate impacts.

In conclusion, while grid decarbonisation has a huge impact on reducing carbon emissions, the implementation of strategies as early as possible is important to minimise cumulative emissions. While the current study provides valuable insights into the impact of climate change, EGCI reductions, and carbon-saving strategies, the exploration of diverse supermarket configurations will further enhance the understanding and optimisation of sustainability practices in the retail sector.

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Nomenclature

Abbreviations

ANL	Argonne National Laboratory
ASHP	Air-Source Heat Pump
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
COP	Coefficient Of Performance
CO_2	Carbon dioxide
DX	Direct Expansion
EEA	European Environment Agency
EGCI	Electrical Grid Carbon Intensity
EU	European Union
GHG	Greenhouse Gas
GWP	Global Warming Potential
HVAC	Heating, Ventilation and Air Conditioning
IPCC	Intergovernmental Panel on Climate Change
LBNL	Lawrence Berkeley National Laboratory
NG	Natural Gas
NREL	National Renewable Energy Laboratory
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory

PV	Photovoltaic
RCP	Representative Concentration Pathway
TEWI	Total Equivalent Warming Impact
TRL	Technology Readiness Level
UK	United Kingdom
WMO	World Meteorological Organisation

Greek Symbols

β	CO_2e emission factor for the combustion of NG [$kgCO_2e/kWh$]

Symbols

E	Electrical consumption [kWh/year]
L	Leakage rate [%/year]
m	Refrigerant charge [kg]
T	Temperature [°C]

About the main author

Elias Eid is a Research Engineer in the Heating and Cooling Research Group at London South Bank University (LSBU). His work focuses on building energy simulations to reduce energy consumption and carbon emissions in the food supply chain by implementing carbon-saving technologies for sustainability. This covers international projects dedicated to decarbonising the European food supply chain. Elias won the 2022/23 Ted Perry Award for Student Research.

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