LIFE CYCLE ASSESSMENT OF DOMESTIC HEAT PUMPS WITH GAS BOILERS AND HYBRID SCENARIO ANALYSIS IN THE UK

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Abstract

This research analyses the environmental impacts of domestic heat pumps with gas boilers and scenario analysis through a life cycle approach. The study analyses three scenarios (Transport (SK), 50% Hybrid and 75% Hybrid) to compare their results with a baseline model and also CE 2050 model which has a future outlook. The results show that changing the manufacturing location from Europe to South Korea doesn't have a significant impact on both models as the weight of manufacturing and transport phases are relatively small compared to the use phase. Hybrid scenario results show increases in GHG emissions; however, the remaining categories have reductions. 50% Hybrid scenario results expect a reduction of 18% and 12% on average in ASHP and GSHP respectively in the baseline model. However, 75% Hybrid scenario results offer less reduction than the half-hybrid scenario in the same model with 8% and 5% decrease in ASHP and GSHP. In CE 2050 model, the results expect an increase of 27% and 21% on average in both heat pumps for 50% Hybrid scenario. On the other hand, CE 2050 model results offer less increase than the half-hybrid scenario for 75% Hybrid scenario with 18% and 13% increase in ASHP and GSHP respectively.

Keywords: Circular Economy, gas boilers, heat pumps, life cycle assessment

1 INTRODUCTION

Heating is responsible for 50% of UK energy use and 35% of GHG emissions and the main source of heat is natural gas currently [1]. Therefore, low carbon heating technologies will play a key role in a Future Homes Standard with their high efficiencies. According to the UK government, future buildings should have 75-80% fewer CO_2 emissions than current built ones with these standards [2]. However, renewable share in heating is still low in the UK with 7.5% [3]. The number of heat pumps sold in the UK is still low and the UK government have plans for not only single heat pump applications but also hybrid use with gas boilers [4]. Therefore, investigating the environmental impacts of hybrid use is also crucial.

This paper aims to compare the environmental impacts of air source heat pump (ASHP), ground source heat pump (GSHP) and gas boiler via scenario analysis. Their impacts have been modelled through a Life Cycle Assessment (LCA) analysis to understand the impacts of manufacturing these technologies in different locations and also using these technologies with a hybrid system.

2 METHODS

Life Cycle Assessment (LCA) methodology [5], [6] has been used for this section to evaluate environmental impacts of low carbon heating technologies (heat pumps) with gas boilers for a domestic application through scenario analysis. The LCA software SimaPro 8.0.3 [7] has been used to model the products and ReCiPe Midpoint (H) method [8] has been used to calculate environmental loads.

System specification and material requirements of heat pumps and gas boilers, and data for these products have been taken from a previous study [9] looking at environmental implications of these products in the UK. However, the study has been conducted in 2010 and there were strong improvements in terms of decarbonisation of electricity mix in the UK. Therefore, the study has been replicated with current electricity mix and future scenarios have been created in line with government targets in our previous study [10]. This study investigates the impact of different manufacturing locations and hybrid options according to Baseline Scenario and CE 2050 Scenario which was modelled in the previous study.

In this study, simulations are done based on assumptions of i) heat pumps manufactured in Europe and transported to UK and ii) manufactured in outside of Europe and transported to the UK. Also, the study investigates the impact of and hybrid heating systems instead of using only one technology.

Table 1 Summary of system specifications and assumptions for scenarios

Drivers		**Baseline**	**CE 2050**
Recycling rates for materials	Steel	62%	78%
	Copper	41%	51%
	Aluminium	90%	100%
	Refrigerant	80%	80%
SPF and Efficiency	ASHP	2.8	4.4
	GSHP	3.9	4.5
	NGB	90%	95%
Efficiency Improvements			25%
Heat Pump Deployment (million)	ASHP	0.126	10.479
	GSHP	0.015	0.178
	Hybrid HP	0.016	7.065
	Gas Boiler	21.989	5.196

Three scenarios are investigated as;

- *Transport (SK) scenario* assumes that heat pumps are manufactured outside of Europe and average ROW (rest of the world) production values have been used in SimaPro. South Korea has been chosen as a manufacturing country to identify the main shipment method and distance as transoceanic freight shipment of 12,400 nm (22,965 km). Table 2 shows the remaining transport methods and distances. In this scenario, underfloor heating system and heat collector production methods haven't been changed.
- *50% Hybrid scenario* assumes half of the energy required for heating has been produced by ASHP or GSHP and the remaining comes from NGB.
- *75% Hybrid scenario* assumes 75% of heating energy has been provided by heat pumps and the remaining 25% produced by gas boiler.

The changes for these three scenarios are done for both baseline model and also CE 2050 model to compare the impacts of these three scenarios in both baseline year and an alternative of year 2050 [10].

Table 2. Transport assumptions of manufacturing in Europe and Asia [9][11]

Transport	**Unit**	**Transport of raw materials**	**Transport of heat pump**	**Transport for installation**
		Transport (SK)		
Rail	km	200		
Truck	km	100	200	400
Sea Freight	km		22,965	
		Transport (EU)		
Rail	km	200	500	
Truck	km	100	200	400
Sea Freight	km			

3 RESULTS

3.1 Baseline Model Results

Transport (SK) Scenario

Transport (SK) scenario results illustrate that changing the manufacturing location does not have a significant impact on most categories when compared to baseline model. ASHP results show that even though the average change is less than 1% there are some categories which have higher results (Figure 1). The highest impact category is MEU with 26% decrease from baseline scenario.[1] TA and PMF categories are other high impact categories with 10% and 6% whereas the change is an increase, unlike MEU category.

When the results illustrated according to life cycle phases the changes occur in manufacturing of heat pump, refrigerant and transport phases as only inputs of these phases are changed (Figure 2). Manufacturing phase increases with an average of 27% in all categories and the highest change occur in TE category with 358% increase. TA, and PMF categories also have high increases with 226% and 58% respectively.

[1] **CC** (Climate Change), **OD** (Ozone Depletion), **TA** (Terrestrial Acidification), **FEU** (Freshwater Eutrophication), **MEU** (Marine Eutrophication), **HT** (Human Toxicity), **POF** (Photochemical Oxidant Formation), **PMF** (Particulate Matter Formation), **TE** (Terrestrial Ecotoxicity), **FE** (Freshwater Ecotoxicity), **ME** (Marine Ecotoxicity), **IR** (Ionising Radiation), **ALO** (Agricultural Land Occupation), **ULO** (Urban Land Occupation), **NLT** (National Land Transformation), **WD** (Water Depletion), **MD** (Metal Depletion), **FD** (Fossil Depletion).

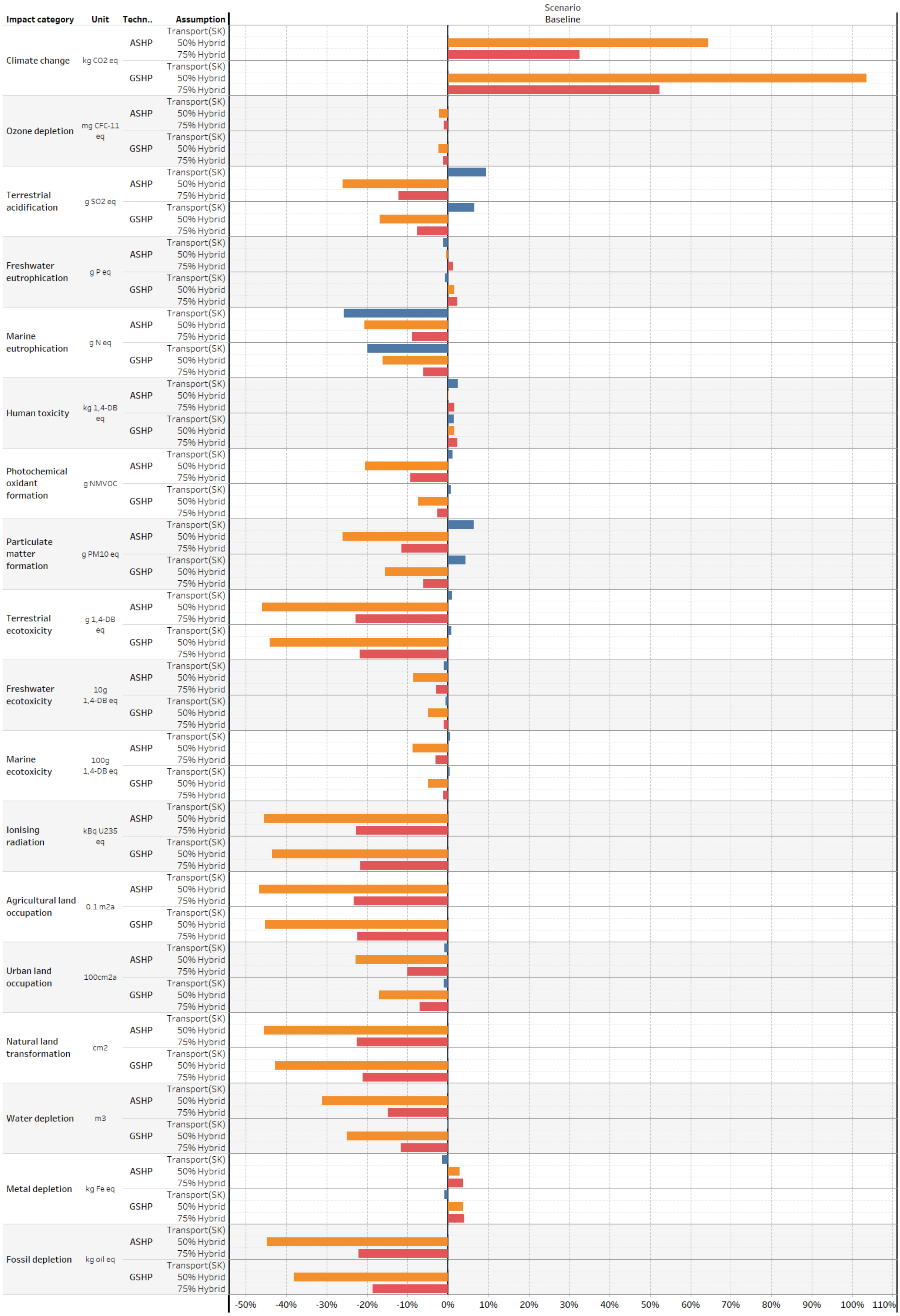

Figure 1 Lifetime environmental impact change of different transport and hybrid scenarios according to baseline model

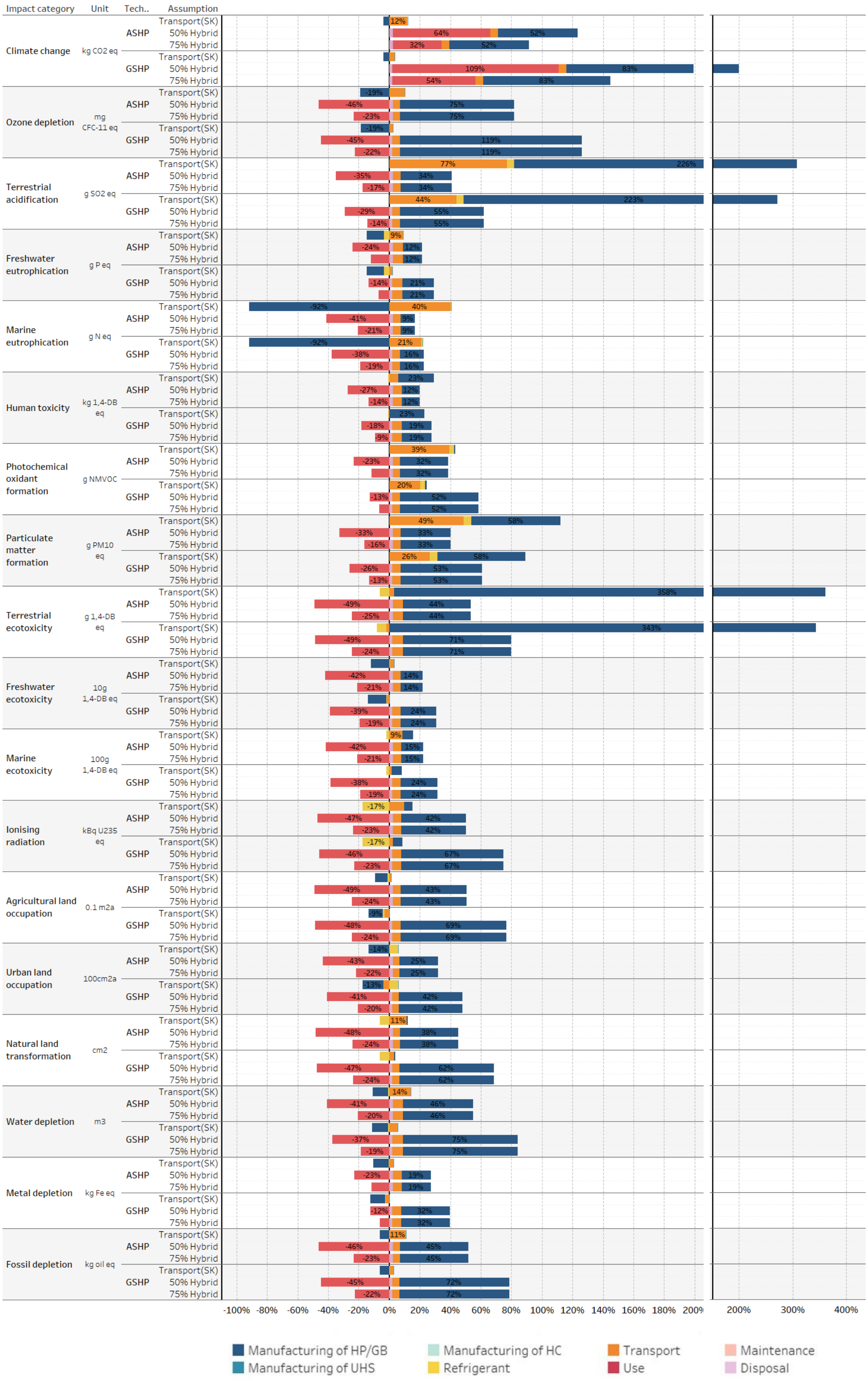

Figure 2 Lifetime environmental impact change of phases for transport and hybrid scenarios according to baseline model

There are also several categories with negative impacts such as MEU and OD categories with 92% and 19% decrease respectively.

Transport phase, on the other hand, increases 17% on average in all categories and the highest contribution comes from TA, PMF, MEU and POF categories with 77%, 49%, 40% and 39% respectively.

Refrigerant phase, however, has a negative impact and results in decrease only 1% on average and the highest change occurs in IR, TE and NLT categories with a decrease of 17%, 6% and 6% respectively. PMF and ULO categories also have 6% change but a positive change with an increase. Results of GSHP shows similarities with ASHP with a decrease of 1% on average (Figure 1). The highest impact category is MEU with 20% decrease following with 7% and 4% increase in TA and PMF categories respectively. The changes in GSHP is relatively lower than ASHP as heat collectors in GSHP will still be manufactured in Europe in this scenario. Therefore, the weight of the change becomes smaller in this technology.

Results of phases are also similar in manufacturing and refrigerant with 26% increase and 1% decrease on average (Figure 2). The highest impact categories are TE, TA, PMF and MEU categories in manufacturing phase, and IR, TE, NLT, PMF and ULO categories in refrigerant like ASHP results. The main difference occurs in transport phase even though the highest categories are the same the changes are less than ASHP.

Hybrid Scenarios

50% Hybrid scenario results expect a reduction of 18% and 12% on average in ASHP and GSHP respectively (Figure 1). GSHP offers higher increase or less reduction in all categories resulting in fewer advantages than ASHP. The highest change occurs in CC category with 64% and 104% increase for ASHP and GSHP respectively. Most categories results with a decrease and the highest decrease occur in TE, IR, ALO, NLT and FD categories varying between 48% and 31% for both heat pumps. Some categories have impact change less than 5% such as OD, FEU, HT and MD categories.

The highest changes occur in use phase with an average of 33% and 26% decrease for ASHP and GSHP and manufacturing phase with 33% and 53% increase for ASHP and GSHP respectively (Figure 2). Transport and disposal phases have an average change of 5% and 2% increase for both heat pumps. Even though the use phase offers a reduction in all categories CC category results in an increase in all phases even use phase. As gas boilers perform worse than heat pumps only in this category in baseline scenario the hybrid scenario offers the worst results in this category. However, in other categories, use phase eliminates the increases created by manufacturing and transport phases as the weight of the use phase is very large and creates negative results in total in all categories.

% Hybrid scenario results offer less reduction than half-hybrid scenario with 8% and 5% decrease in ASHP and GSHP (Figure 1). Similarly, GSHP performs worse than ASHP in this scenario with an increase in CC category and decrease in other categories. However, this scenario offers less increase in CC category and less decrease in other categories as the contribution of gas boiler is less than 50% Hybrid scenario. The highest change occurs in CC category with 33% and 52% increase for ASHP and GSHP. The highest decreases occur in TE, IR, ALO, NLT and FD categories varying between 23% and 18% for both heat pumps.

3.2 CE 2050 Model Results

Transport (SK) Scenario

Transport (SK) scenario results show that changing the manufacturing location could increase the environmental impacts on average 15% and 2% for ASHP and GSHP respectively according to CE 2050 model (Figure 3). The highest changes for ASHP occur in TA, POF and PMF with 33%, 18% and 275% increase. Also, results suggest a decrease in several categories with less than 3% except for MEU category which has 48% reduction from CE 2050 model. GSHP results expect lower values than ASHP in all categories but the highest contributors are the same impact categories.

The life cycle phase results illustrate that the highest contributor phases to the changes from CE 2050 model are manufacturing of heat pump, refrigerant and transport phases similar to baseline model (Figure 4). The results of changes in these phases are the same with baseline model, therefore, the changes in these phases have the same impacts in both baseline and CE 2050 model.

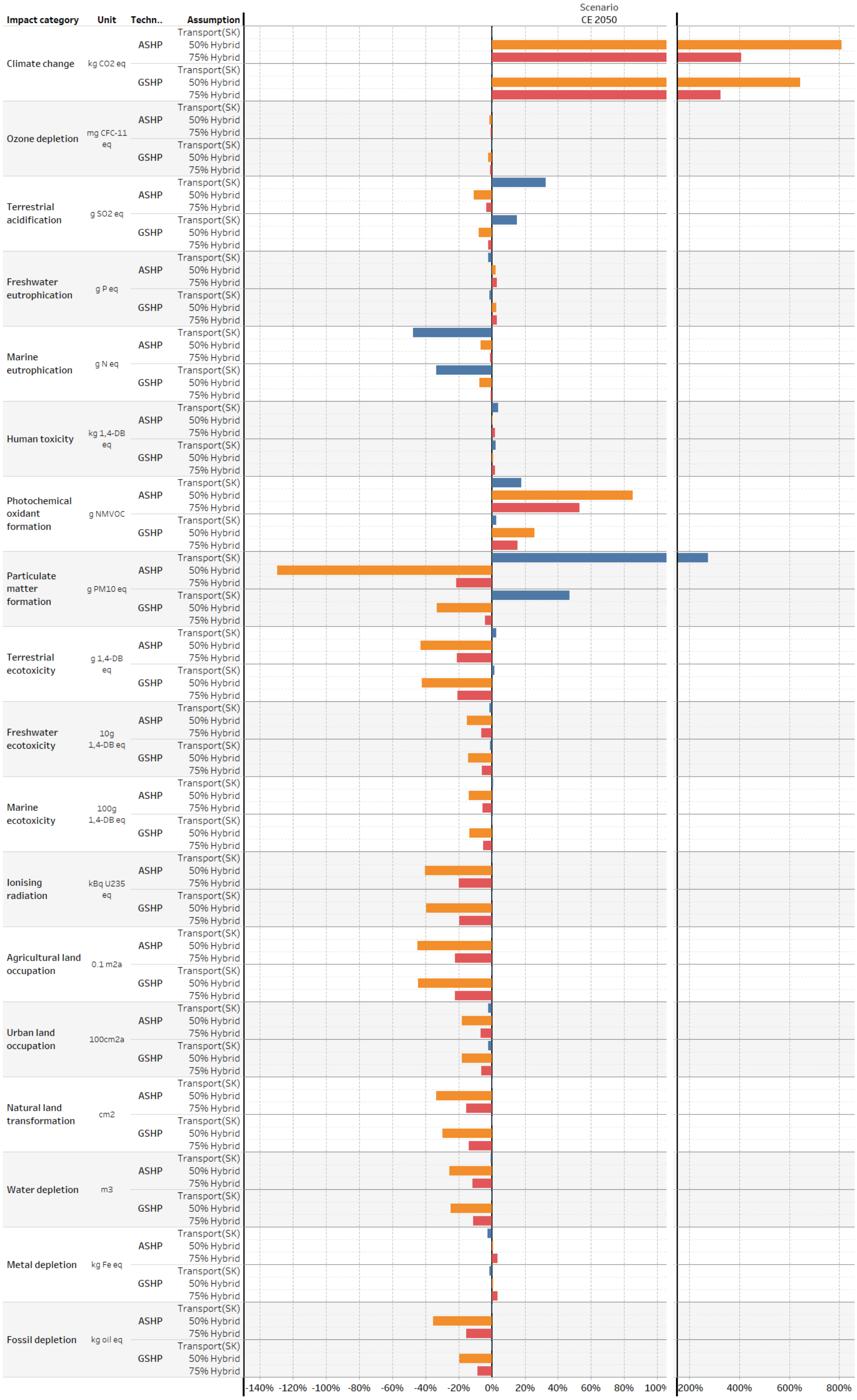

Figure 3 Lifetime environmental impact change of different transport and hybrid scenarios according to CE 2050 model

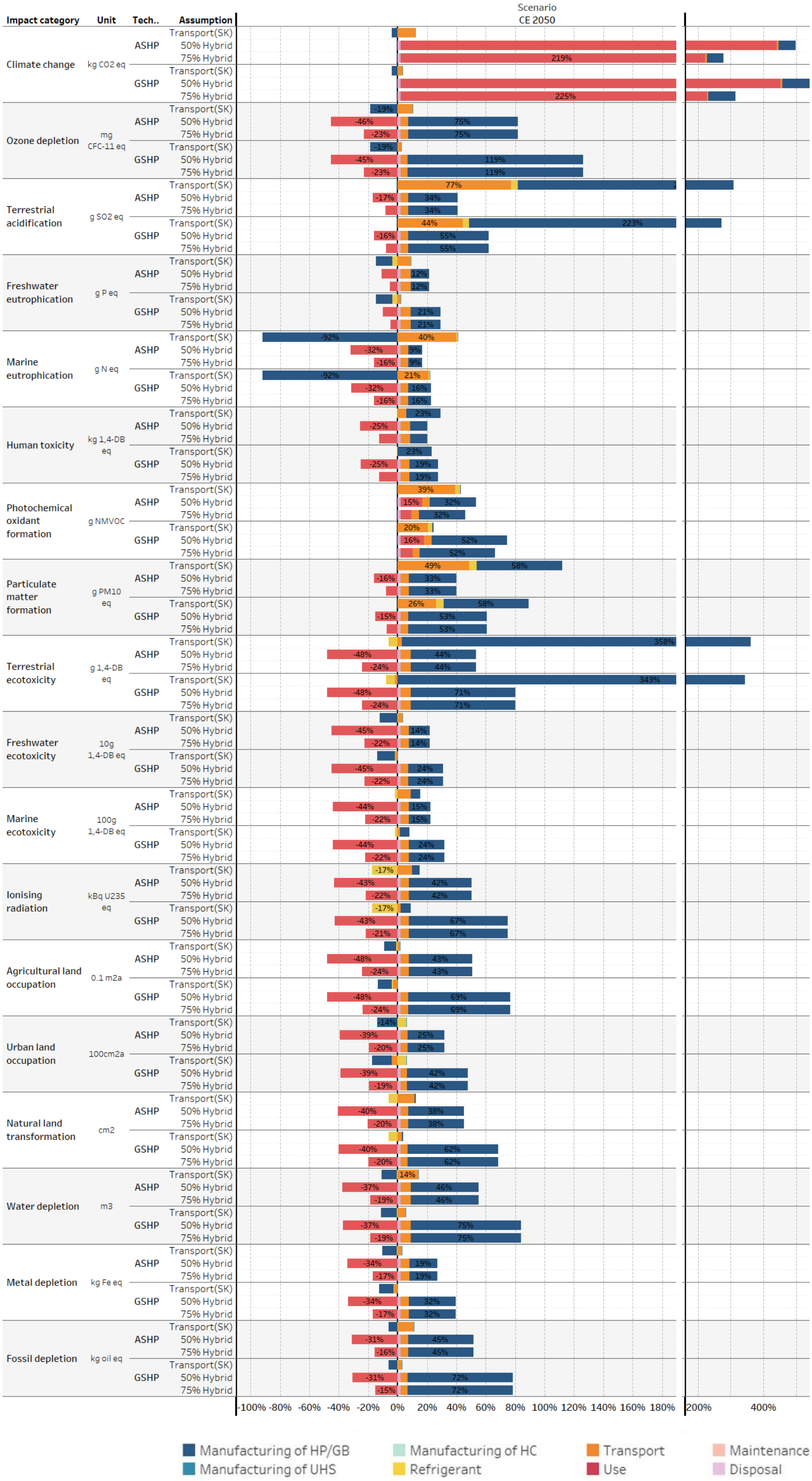

Figure 4 Lifetime environmental impact change of phases for transport and hybrid scenarios according to CE 2050 model

Hybrid Scenarios

Even though different manufacture scenario has the same results in baseline and CE 2050 model, hybrid scenarios have significant differences as they are affecting the use phase. 50% Hybrid scenario results expect an increase of 27% and 21% on average in ASHP and GSHP respectively (Figure 3). The highest changes are in CC category with 810% and 645% increase for ASHP and GSHP similar to baseline model. Other category suggesting an increase is POF with 85% and 26% for both heat pumps. Most of the remaining categories have a reduction around 15%-45% except PMF category which has 130% reduction for ASHP and 33% for GSHP.

The results of phases illustrate that the highest changes occur in the manufacturing phase with 33% and 53% increase on average for both heat pumps (Figure 4). Transport and disposal phases also create an increase of 5% and 2% respectively. However, the use phase suggests a decrease around 5% on average for both heat pumps. Similar to baseline model, use phase offers a reduction in all categories except CC category which suggests an increase with 64% and 109% for ASHP and GSHP respectively. FEU, HT, POF, PMF and MD categories have a reduction varies between 12%-30% whereas remaining categories expects higher reductions varying between 40%-50%. In CE 2050 model, hybrid scenarios offer an increase on the contrary of baseline model mainly because the weight of use phase is lower in CE 2050 model.

Similar to baseline model, 75% Hybrid scenario results offers less increase than half-hybrid scenario with 18% and 13% increase in ASHP and GSHP respectively. The highest change occurs in CC category with 408% and 325% increase for ASHP and GSHP. The highest decreases occur in TE, IR, ALO, NLT and FD categories varying between 22% and 15% for both heat pumps.

The changes in manufacturing, transport and disposal phases are similar to baseline model in both hybrid scenarios so there is no difference between baseline and CE 2050 model and 50% and 75% Hybrid scenarios in these phases except use phase.

4 DISCUSSION AND CONCLUSION

Changing the manufacturing location from Europe to South Korea does not have a significant impact on both baseline and CE 2050 model, however, the results slightly higher in CE 2050 model as the weight of use phase is lower due to efficiency improvements in houses and low-carbon technologies so the remaining phases comprise higher shares. As the main contributor to these changes is manufacturing phase, better production lines through adapting CE principles could help to reduce the impact of manufacturing phase.

Hybrid scenario results expect an increase in GHG emissions as boilers use a fossil fuel; however, the negative impacts from remaining categories decreases. In both hybrid scenarios, the overall results suggest a reduction in baseline model even though 75% Hybrid scenario shows less decrease. However, the results suggest an increase in CE 2050 scenario, and 75% Hybrid scenario shows lower values again. The changes are greater in CE 2050 model as heat demand in the future will be relatively small, therefore, the importance of use phase will be higher to reduce the negative impacts.

Life cycle analysis results show better values for heat pumps in climate change category with less CO_2 emissions whereas they perform worse in the remaining impact categories. Therefore, applications of hybrid options via integrating heat pumps with gas boilers could help to reduce negative impacts.

The limitation of Transport (SK) scenario is, even though South Korea is used as manufacturing location, rest-of-the-world (RoW) data for production assumptions and input data has been used in SimaPro due to the lack of data availability.

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