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Moving towards low-carbon manufacturing in the UK automotive industry

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Abstract

The automotive industry is facing on-going challenges to improve the sustainability of its manufacturing processes and vehicle emission. Policies are one of the main drivers towards low-carbon manufacturing. In this work, the UK regulations in terms of environment, energy-efficiency and resources management and the ISO Standards concerning the automotive sector have been identified and described. The environmental benefits obtained in terms of energy consumption, waste production, water consumption, and air quality by a more efficient vehicle production for the UK manufacturers are presented. Current thermal energy management practice and strategies to increase the energy efficiency of the automotive manufacturing process are described. It is concluded that manufacturing processes and plants are both in need of modifications to achieve low-carbon manufacturing and produce low or zero emission vehicles.

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1. Introduction

The automotive manufacturing sector is facing a growing number of new challenges. This is due to the recent significant increase in the overall vehicle production, together with a rise in energy cost and environmental responsibilities. Table 1 compares the vehicles produced by 32 automotive manufacturers across the UK and their environmental burdens in 2000, 2015 and 2016 [1], which indicates a total production of 1.82 million vehicles consuming 4.673 TWh of energy and emitting 1.344 million tonnes of CO₂ in 2016. Also shown in Table 1, the

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environmental impact produced by the automotive manufacturing process in the last few years has been significantly reduced. While the production numbers in 2016 have reached the same level as in 2000, the energy consumption and emissions have been reduced. However, following the recent growth trend, this number is likely to increase in the future, therefore automotive manufacturers are looking for more energy-efficient and sustainable processes. The main drivers of this interest are economic, environmental, marketability and policy reasons [2].

Table 1. Consumption and production data UK automotive manufacturing, adapted from [1].

Year	Total vehicles produced [millions]	Total energy use [GWh]	Energy use per vehicle [MWh/unit]	Total water use [m ³]	Water use per vehicle [m ³ /unit]	Total CO _{2,eq} produced [tonnes]	CO _{2,eq} per vehicle [tonnes/unit]	VOCs* emissions [g/m ³]	Total combined waste to landfill [tonnes]	Waste to landfill per vehicle [kg/unit]
2000	1.8	7,013	3.9	6,090	5.3	2,182,926	1.1	55.0	80,399	40.3
2015	1.68	4,588	2.07	5,344	2.5	1,316,989	0.58	33.6	4,415	2.0
2016	1.82	4,673	2.00	5,516	2.4	1,344,026	0.56	32.2	3,180	1.4

* Volatile organic compounds (VOCs)

As the automotive manufacturing is a complex and an energy intense process, it consumes a significant quantity of raw materials and water, an evolution of the automotive manufacturing process is required to move towards low-carbon emissions and increased sustainability of the process. The study investigates the policies, standards and practice employed in the UK to ease the development of a more sustainable process. In Sections 2-5, the UK policies, current thermal energy management practice, identified strategies for the development of low-carbon manufacturing and conclusions are presented.

2. UK policies and standards for the automotive industry – a quick glance

To tackle climate change, energy efficiency policies and environmental regulations have been implemented. Table 2 summarises the UK policies concerning the automotive sector for the realisation of an energy-efficient and environmentally friendly process to manufacture the same products with lower energy input and ultimately reduced greenhouse gas (GHG) emissions.

Table 2. UK energy-efficiency policies.

Policy and description	Key points
<i>Climate Change Levy (CCL)*</i> - an environmental tax introduced in 2001 on energy delivered to non-domestic users [3].	<ul style="list-style-type: none"> Tax is added for energy sources such as electricity, gas, propane (LPG) and coal supplied to industrial, commercial, agricultural, public and service sectors.
<i>Climate Change Agreement (CCA)*</i> - an agreement introduced in 2001 between energy-intensive industries and UK government to cut energy consumption and GHG emissions [4].	<ul style="list-style-type: none"> Agreements are based on energy efficiency or carbon emission improvement strategies. Financial incentives are provided for companies who are able to meet the conditions of their agreement based on a reduction of 90% of CCL on electricity consumption and 65% on gas consumption and exemption from Carbon Reduction Commitment (CRC). Automotive manufacturers are also eligible for paint shops, boilers, press shops and plastic injection moulding.
<i>EU – Energy Trading Scheme (ETS)</i> - an EU mandatory cap and trade scheme introduced in 2005 (currently in Phase III 2013-2020) based on putting a cap on the GHG production and creating a favourable market for producers able to cut their emission, respecting their carbon “allowances” [5].	<ul style="list-style-type: none"> The scheme fixes the maximum producible amount of carbon emissions (cap), allowing companies to consume less and sell or keep any spare carbon “allowances” for future needs. It gives an economic value to energy-efficiency. All combustion activities in the automotive manufacturing process, such as gas used in boilers and heating systems are included in the EU-ETS.
<i>Carbon Reduction Commitment (CRC) Energy Efficiency Scheme</i> - a UK mandatory cap and trade scheme introduced in 2010 (currently in Phase II 2014-2019) on carbon emissions [6].	<ul style="list-style-type: none"> Carbon tax is added on all energy-related carbon emissions for non-energy intensive and public and private users not already covered by the CCA or EU-ETS. The qualifying criterion is the electricity consumption. This tax will be abolished in 2019 but to compensate for this loss of revenue, CCL will significantly increase

Energy Saving Opportunity Scheme (ESOS) - a mandatory assessment introduced in 2014 (currently in Phase II 2015-2019) on energy use and efficiency improvement opportunities, which must be performed once every 4 years [7].

- in that year.
- Audit scheme is implemented based on the measure of total energy consumption, identification of energy-efficient and cost-effective solutions. It includes possible energy saving opportunities for automotive manufacturers in body pre-treatments and painting processes, boiler and heating systems, effluent treatment plants, press shops, foundries for casting components etc..

* CCL and CCA are considered as energy-efficiency (which is more commonly adopted in the UK) and environmental policies as the agreements between industry and the UK Government are based on either energy consumption or carbon emission.

To comply with energy and environmental policy requirements, automotive manufacturers have started to implement energy, environmental and quality management systems recommended by the International Organisation of Standards (ISO) including [8-10]. By implementation of a **systematic, planned and well-documented** management system based on the **plan, do, check and act** principle, automotive manufacturers could benefit from remarkable savings in terms of energy and material consumption. Table 3 summarises the standards mainly involved in the management of energy sources and materials for the automotive sector.

Table 3. ISO Standards used in the automotive manufacturing sector.

Standard and description	Key points
<i>ISO 50001: 2011 Energy Management Systems – Requirements with Guidance for Use</i> to assist organisations to reach economic savings through a better management of the energy sources [8].	<ul style="list-style-type: none"> • The Standard enables organisations to realise a periodically revised and improved policy for better energy resources management, targets setting and strategies implementation with reduced energy consumption and costs.
<i>ISO 14001: 2015 Environmental Management Systems</i> for the management of an organisation’s environmental program [9].	<ul style="list-style-type: none"> • The Standard enables organisations to minimise water usage and waste production based on design, pollution prevention and end-of-life waste recycling to comply with environmentally-oriented regulations.
<i>ISO/TS 16949:2016: ISO Technical Specification for Quality Management</i> for the development of a quality management system [10].	<ul style="list-style-type: none"> • This sector-specific quality management standard is developed based on defects reduction to reduce waste and material consumption.

Environmental policies regulate the management of waste and air pollution resulting from the automotive production process. As shown in Table 4, the UK has not independently developed any national policies on waste, pollution prevention and air quality but adopted existing EU policies for the automotive industry.

Table 4. UK ambient policies for automotive manufacturing sector.

Sector	Regulation and description
Waste management	<ul style="list-style-type: none"> • End-of-Life-Vehicle (ELV) Directive was introduced in 2000 by the EU to increase the reuse, recycling and recovery of the vehicles, forcing the automotive manufacturers to reutilise and recover a minimum of 95% by weight and by year of their products since 2015 [11].
Pollution prevention and air quality	<ul style="list-style-type: none"> • REACH Regulation was introduced in 2007 by the EU on the utilisation and emission of chemical substances by industry. The handling and emission of Volatile Organic Compounds (VOCs) released by the painting process is particularly regulated for the automotive sector [12].

3. Current thermal energy management

Energy efficiency is hence one of the key drivers of the current automotive manufacturing. Thermal energy recovery, management and utilisation is a central strategy to leverage the present excess heat for the realisation of an efficient manufacturing process. The vehicle production process involves different treatment steps and heating/cooling processes. An automotive manufacturing process which is commonly practised by the UK manufacturers and the related energy distribution is shown in Fig. 1. Equipped with paint booths, ovens, waste treatment system, *etc.*, the paint shop is the largest energy consumer during automotive manufacturing processes. In

fact, a higher paint quality, a shorter time period required for paint drying and an increase in the production chain can be achieved by excellent temperature and humidity control in the paint shop. Currently, the temperature and humidity in the manufacturing plants are managed by running conventional air handling units including heaters and cooling systems. Typically these are electrically-driven units which are energy inefficient and they are unable to deal promptly with changes in the outdoor humidity conditions. Current thermal energy management strategies are summarised in Table 5.

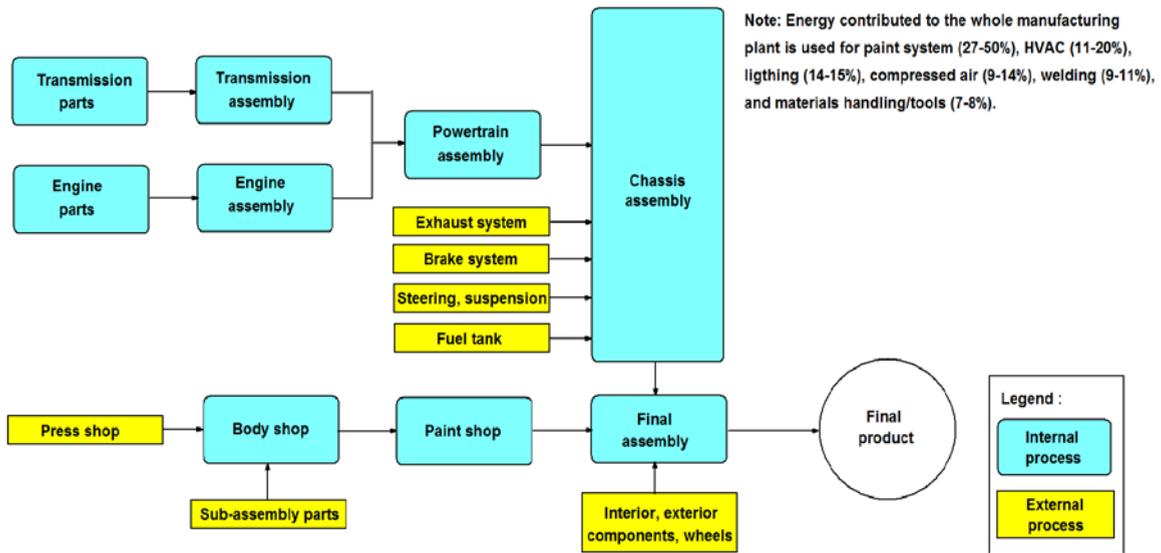


Fig. 1. Automotive manufacturing process and energy-related distribution, adapted from [2].

Table 5. Current thermal energy management in the automotive manufacturing plant.

Facility/process/system	Heat utilisation and recovery
Body shop	<ul style="list-style-type: none"> Heat recovery from casting and metal treatment.
Paint shop	<ul style="list-style-type: none"> Exhaust air recovery from paint booth. Control of temperature and humidity for paint booth supply air with desiccant wheels.
Powertrain assembly	<ul style="list-style-type: none"> Heat recovery from casting and metal treatment.
Heating, ventilation and air-conditioning (HVAC)	<ul style="list-style-type: none"> Solar thermal heating. Heat pumps.
Compressed air systems	<ul style="list-style-type: none"> Space heating, industrial process heating, drying, etc. Hot water production for thermally-driven cooling/dehumidification technology (e.g. solid desiccant and absorption chillers).
Boilers	<ul style="list-style-type: none"> Heat recovery from flue gas to preheat boiler feed-water in an economiser. Hot condensed water recovery. Steam recovery from blowdown used for space heating and feed-water preheating.
VOC removal system	<ul style="list-style-type: none"> Heat recovery from Regenerative Thermal Oxidiser (RTO) for cooling production with absorption chiller.

As reported by [13], significant energetic, economic and environmental benefits can be obtained by the realisation of an on-site heat recovery network to considerably reduce the cost of the heating, cooling, and paint drying processes, which are currently mainly performed with the use of fossil fuel and electricity. A reduction in the energy consumption of 16% was obtained in the case study. The RTO heat recovery for cooling production is currently recognised as a viable and economic strategy if it is considered in the design of the manufacturing plant. In addition, combined heat and power (CHP) systems which supply electricity, steam and heat required by the manufacturing process simultaneously have been explored by the manufacturers. The energy efficiency of the process can be increased by the use of CHP systems because of the exploitation of waste heat. This is particularly important for manufacturing processes with year-round demand for heat, such as the paint shop, where the

utilisation of CHP can result in a reduction of the production costs and of the resulting environmental impact. Additional economic savings can be obtained by integrating CHP with absorption cooling technology (tri-generation system). Also, reduced heating/cooling loads in the manufacturing plant obtained in the last few years due to the employment of LED-efficient lights, artificially-driven lighting, better insulation of building envelopes, etc. has resulted in important benefits in terms of economic and environmental performance.

4. Moving towards low carbon manufacturing

To decarbonise the automotive sector, several improvements must be made in connection with emission of the manufacturing process and of the vehicles. Sustainability can be obtained by the realisation of a painting process to efficiently deal with temperature and humidity required by the supply air. This could significantly reduce the consumption of the energy currently used for HVAC in the plant. The opportunity of storing the excess heat present in the plant in the form of thermo-chemical energy in concentrated desiccant solution and transporting it without energy losses on-site is a research subject that will be investigated by automotive manufacturers in the future. As manufacturing process requires several steps of heating, cooling and drying, the multifunction ability of such district network for heating/cooling and (de)humidification [14] makes the technology very appealing to automotive manufacturers.

In 2018, an Automotive Sector Deal has been established between the UK government and automotive manufacturers, determining aims and long-term strategies for the sector [15]. This deal, which will be reviewed annually, has identified different business opportunities for the realisation of a low-carbon economy for the sector. The realisation of ultra-low or zero emission vehicles is one the main strategies identified. Amongst the feasible technologies, the development and commercialisation of free-piston engines is considered worthy of interest [16]. The development of these engines have particularly interested automotive manufacturers for the realisation of hybrid electric vehicles powertrain. In fact, electrification of vehicles, such as battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCEVs), is considered as a top priority for low carbon automotive. A higher market share for the electric vehicle sector is expected in the future in the UK, reaching significant values by 2030 [17]. Additionally, the UK is expected to be one of the main manufacturers of Connected and Autonomous Vehicles (CAVs). The realisation of driverless cars is expected in the UK roads by 2021 [15]. In their so-called “eco-driving mode”, these vehicles could result in effective benefits, caused by a reduction in the energy consumption and an increase of the safety of the drive. All these require modifications in the automotive manufacturing process to adapt to the new challenges, such as the production of transmission systems for electric vehicles, electric motors, and batteries, and the associated electronics needed to control them. In addition, battery disposal and recycling is a subject that must be taken into account for the evaluation of the sustainability of the process. As such, remarkable opportunities for the future automotive manufacturing are present. For an effective utilisation of the available sources, a circular economy strategy has been identified as a possible tool for enhancing the sustainability of the process, ensuring less market fragmentation and a better use of the resources [17]. Through the implementation of this business strategy established between different organisations, such as automotive manufacturers, material and component suppliers, and based on redesign of the supply chain, on reorganisation of material flows obtained by remanufacturing of components, reduction and reutilisation of waste, and on prolonged life of the vehicle, it is possible to obtain energy and material savings while obtaining remarkable benefits in terms of environmental burdens and energy consumption.

5. Conclusions

As the automotive manufacturers are facing economic and environmental pressures for the realisation of a sustainable low-carbon process, improved energy efficiency is necessary to decrease GHG emissions. This work is important as it offers insights into the current policies, thermal management practice and strategies towards low-carbon manufacturing in the UK:

1. The UK policies aim to promote the efficiency of the energy and resource consumption, produce a cost benefit in the realisation of the strategies and identify energy saving opportunities during automotive manufacturing process. To comply with UK regulations, automotive manufacturers have implemented ISO energy,

- environmental, and quality management standards and obtained benefits in terms of energy and resources consumption.
2. A better humidity control strategy could result in reduced energy consumption of the HVAC in the manufacturing plants, enhanced paint quality and increased productivity. Excess heat recovery during manufacturing processes is one of the main approaches to increase its energy efficiency for economic savings and environmental benefits.
 3. The transition to low or zero emission vehicles, which requires modifications in the manufacturing processes, is a key milestone for carbon footprint reduction in the sector. However, the shift towards innovative and low-carbon manufacturing processes needs further development. Even if significant steps towards energy efficiency have been made by the automotive sector, long-term strategies are still needed towards the realisation of a low-carbon sector.

The outcomes of the study can benefit the stakeholders in the automotive sector including policy makers, manufacturers and researchers in making decisions and defining scope as well as direction for immediate focus. Future work should present how the UK policies influence the economic feasibility of heat recovery and utilisation process in the automotive manufacturing plants and how these could be modified to help the marketability of the UK automotive manufacturing process.

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