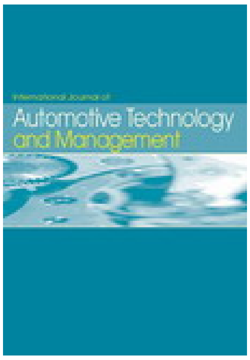

International Journal of Automotive Technology and Management

ISSN online: 1741-5012 - ISSN print: 1470-9511
https://www.inderscience.com/ijatm

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DOI: 10.1504/IJATM.2024.10063047

Article History:

Received:	20 October 2023
Last revised:	31 October 2023
Accepted:	05 November 2023
Published online:	07 May 2024

From ICE to BEV production in Europe: industry geography in transition

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Abstract: This paper describes the distribution of battery electric vehicle (BEV) production in Europe and suggests explanations for the distinctive spatial pattern of BEV production that is unfolding in Europe. We show that the emerging distribution of final assembly plants and battery plants for BEV production varies from the existing distribution of assembly and engine operations for internal combustion engine (ICE) vehicle production. Economic geography factors underlying the distribution of motor vehicle production, including agglomeration and co-location, remain important in understanding Europe's emerging geography of BEV production, yet factors unique to BEVs are altering the spatial pattern of production within Europe.

Keywords: Europe; auto industry; production geography; vehicle assembly; battery production; electric vehicles; ICE vehicles.

Reference to this paper should be made as follows: Klier, T.H. and Rubenstein, J.M. (2024) 'From ICE to BEV production in Europe: industry geography in transition', *Int. J. Automotive Technology and Management*, Vol. 24, No. 1, pp.95–117.

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This paper is a revised and expanded version of a paper entitled 'From ICE to BEV production in Europe: industry geography in transition' presented at the 2023 International Colloquium of Gerpisa, Brussels, 29 June 2023.

1 Introduction

This paper discusses the evolving geography of the motor vehicle industry in Europe, with a focus on the transition from internal combustion engine (ICE) vehicles to battery electric vehicles (BEVs). We describe the current footprint of BEV production in Europe and compare it to Europe's current distribution of ICE vehicle production.

Most ICE vehicles sold in Europe are assembled in Europe, with engines produced in Europe. Economic geography factors, including economies of scale and agglomeration economies, help to explain this pattern. How does the transition to BEVs impact the industry footprint? At this early stage in the transition from ICE vehicle to BEV production, some geographic patterns are emerging, and others are still uncertain. What factors help to understand the emerging geography of BEV assembly and battery production in Europe? Which of these factors are comparable to those that have explained the geography of ICE vehicle and engine production, and which factors may impact changes in the geography?

Historically, Europe's motor vehicle industry was highly clustered in a core area centred around Germany and France. "The internal combustion engine was first perfected in Germany and France, and it is unequivocal that Continental automobile manufacturers were at least a decade ahead of their British and American counterparts in the technological development of the gasoline automobile" [Flink, (1990), p.11]. During the 1880s, Gottlieb Daimler and Carl Benz built the first commercially viable motor vehicles in Germany [Flink, (1990), pp.11–13]. In 1900, "Paris was the center of the nascent automobile industry" [Flink, (1990), p.15]. The French company Panhard et Levassor (P&L) was the world's leading car company. P&L pioneered the modern ICE vehicle design, with the engine in the front, a transmission driving rear wheels, and passengers sitting in a compartment between the front and rear wheels [Womack et al., (1990), p.22].

Into the 21st century, new motor vehicle factories have increasingly favoured peripheral areas (Brincks et al., (2016), p.2; Lung, 2004). Sweeping political change in Central Europe beginning in 1989 led to manufacturing integration, especially at the regional level [Brincks et al., (2016), pp.9–10]. See Klier and Rubenstein (2021) for a description of the industry's footprint in Europe during the 2010s, a decade that may ultimately be regarded as the peak decade of ICE production.

Early in the industry's history, before a dominant power source had emerged, electricity powered many vehicles (Kirsch, 2000). In Europe, Gustave Trouvé is credited with building the first BEV and operating it in Paris in 1881 [Wakefield, (1994), p.2]. In the USA, BEVs accounted for 38% of vehicles sold in 1900, and the best-selling model that year – the electric-powered Columbia–became the first car ever to exceed 1,000 in annual sales [Rubenstein, (2001), p.244]. By the 1910s, though, gasoline had become the dominant fuel, and ICE vehicles accounted for nearly all production in Europe and the USA.

As recently as 2010, there were only around 10,000 electric vehicles (EVs)[1] in the world, according to IEA; the world-wide stock of EVs first exceeded 1 million vehicles in 2015 and topped 10 million vehicles in 2020 [IEA, (2021), p.7]. The world-wide market share for EVs exceeded 1% of new vehicles sold for the first time in 2017 and reached 10% for the first time in 2022.

The two leading markets for EV sales have been China and Europe; the two regions together accounted for 84% of worldwide EV sales in 2022. In 2022, EVs held 23% of total vehicle sales in China and 14% in Europe. European Union CO_2 emissions standards and subsidy programs helped to stimulate EV production and sales.

In light of the ongoing transition away from ICE vehicles, this paper compares the distribution in Europe of BEV and battery production with the distribution of ICE vehicle and engine production. We find that in Europe the current distribution of BEV production differs noticeably from that of ICE vehicle production.

2 Economic geography principles underlying vehicle production

Two economic geography factors underlie the distribution of motor vehicle production in Europe, as well as in other regions: economies of scale and agglomeration economies. Economies of scale are "the cost advantages gained by large-scale production, as the average cost of production falls with increasing output" [Gregory et al., (2009), p.183]. "Agglomeration economies are the benefits that come when firms and people locate near one another together in cities and industrial clusters" [Glaeser, (2010), p.1].

2.1 Economies of scale

Economies of scale influence how many plants are needed for the various steps in motor vehicle production [Klier and Rubenstein, (2015), p.104; Lung, 2004; Truett and Truett, 2001, 2003; Wynn-Williams, 2009). "The actual manufacture of vehicles can be divided into a number of distinct operations, each with its own optimum scale" [Rhys, (2005), p.264]. Wynn-Williams (2009), citing Rhys (1972) and Wells and Rawlinson (1994), outlines four fundamental processes in vehicle production, each with distinctive economies of scale: research and development of new models; pressing (stamping) of steel sheets and welding them into vehicle body panels; fabrication of engines and transmissions; and final assembly of vehicles [Wynn-Williams, (2009), pp.41–42]. The volume needed to attain minimum economies of scale varies for each of the four processes [Klier and Rubenstein, (2021), p.326; Husan, (1997), p.40].

For example, economies of scale in powertrain production are substantially larger than those in vehicle assembly. Klier and Rubenstein (2021) found that in 2016 Europe had 75 final assembly plants producing at least 50,000 vehicles annually, compared with only 40 engine plants. Mean annual production in 2016 in Europe was 241,000 in final assembly plants and 522,000 in engine plants [Klier and Rubenstein, (2021), p.326].

A feature related to the differences in economies of scale in vehicle and engine production is that engines are typically not unique to individual vehicle models but are shared across a range of models. This approach is common to all large volume vehicle producers, as engines not only exhibit larger economies of scale than vehicle production, but also have different, typically much longer, development and production cycles (Center for Automotive Research, 2017). As production transitions to BEVs, economies of scale remain important, according to Huth et al. (2013). "Scale effects in the manufacturing process [of batteries] are fundamental and lead to high costs for low volumes" [Huth et al., (2013), p.79].

2.2 Agglomeration economies

The motor vehicle industry, while global in nature, is highly regionalised into three major production areas: Europe, North America, and East Asia [Head and Mayer, 2019; Layan, (2000), p.122]. Most vehicles sold in Europe are assembled at plants in Europe, and similarly most vehicles sold in North America and in East Asia are assembled at plants in those respective regions (Klier and Rubenstein, 2015, 2021, 2022b; Mordue and Sweeney, 2020; Pavlínek, 2018, 2020, 2022; Pavlínek and Ženka, 2011).

Agglomeration economics underlie the pattern of assembling most vehicles in the same region as they are sold (Klier and Rubenstein, 2015, 2021, 2022a). Motor vehicle production is highly agglomerated because it is a good example of what Weber (1929) called a bulk-gaining industry (Brincks et al., 2018). A bulk-gaining industry is characterised by a fabricated product that is heavier and occupies a greater volume than its inputs [Rubenstein, (1992), p.11]. To minimise the aggregate costs of bringing in raw materials and shipping out finished products, final assembly in a bulk-gaining industry, such as motor vehicles, tends to locate near consumers [Klier and Rubenstein, (2015), p.205; (2022b), p.6].

2.3 Powertrain supply chain footprint

Spatial agglomeration reinforces the interdependency between car manufacturers and their suppliers [Lung, (2004), p.157]. “[C]lustering behavior at each step of the production process has tended to strengthen due to the complexity of the automobile product” [Lung, (2004), p.153]. A high degree of co-location exists between the location of final assembly plants and the location of powertrain plants that produce the engines and transmissions. In other words, most engines and transmissions are manufactured near where they are installed in vehicles – that is, at the final assembly plants (Klier and Rubenstein, 2021).

In terms of corporate structure, historically, carmakers achieved economies of scale and agglomeration through vertical integration (Flink, 1990). Since the late 20th century, they have out-sourced production of most vehicle parts to independent suppliers (Klier and Rubenstein, (2008), pp.31–53; (2021), p.327; Womack et al., (1990), pp.33–34].

The ICE powertrain represents an exception to the outsourcing trend. Powertrain production typically involves three steps: casting, machining, and assembly (Davis, 2013; Klier and Rubenstein, 2008). Carmakers regard a vehicle’s powertrain as a key core competency, so have mostly retained control of the assembly step (Huth et al., 2013; Klier and Rubenstein, 2008; Manello and Calabrese, 2015). The other two functions are sometimes outsourced to independent suppliers [Henry, 2017; Klier and Rubenstein, 2008; (2021), pp.324–325].

Specifically, engines remain an almost exclusively vertically integrated part: Only 5% of engines are outsourced to independent suppliers in North America and 1% in the European assembly plants included in our study [Klier and Rubenstein, (2021), p.328].

3 Europe’s production subareas

Motor vehicle production historically clustered in centrally located core areas (Klier and Rubenstein, 2015). Around 1990, two key economic and political events had a profound impact on Europe's motor vehicle industry: The dismantling of the Iron Curtain and the subsequent Treaty on the European Union. These events encouraged a change in the distribution of production within Europe [Brincks et al., (2016), p.132]. The Treaty on European Union ushered in a uniform region-wide regulatory framework for energy efficiency, pollution standards, and other technology [Lung, (2003), p.3]. The dismantling of the Iron Curtain considerably enlarged the definition of the market area of a unified Europe in a relatively short time.

3.1 Identifying subareas

It is now common practice to distinguish three subareas when analysing motor vehicle production. The three subareas are referred to as core, semi-periphery, and integrated periphery (Brincks et al., 2018; Chanaron, 2004; Domański and Lung, 2009; Lung, 2004; Mordue and Sweeney, 2020; Pavlínek, 2022).[2] Allocation of specific countries among the three subareas can vary slightly, depending on the precise criteria used in the study (Pavlínek, 2022). For this study, countries are allocated as follows:

- Core: France, Germany, Italy.
- Semi-periphery: Austria, Belgium, Finland, the Netherlands, Portugal, Spain, Sweden, the UK.
- Integrated periphery: Czechia, Hungary, Poland, Romania, Slovakia, Slovenia.[3]

Europe's *core* subarea is centred on western Germany and northern France (Jürgens and Krzywdzinski, 2008; Lung, 2004). France, Germany, and Italy have been grouped as Europe's core for vehicle production, because these three countries were home to the headquarters of the region's largest volume manufacturers, and they clustered the largest share of their production facilities in their home countries.

The establishment of the Common Market in 1958, with its subsequent successors and expansions, promoted the opening of assembly and powertrain plants outside the traditional core production areas, especially in Spain. This area is now known as *semi-periphery*. The term semi-periphery applies to an automotive-producing country with a relatively high GDP that (unlike a core country) lacks a domestically headquartered automaker [Mordue and Sweeney, (2020), p.35].

Since the 1990s, vehicle production has grown considerably in the *integrated periphery* (Brincks et al., 2018; Chanaron, 2004; Domański and Lung, 2009; Humphrey and Oeter, 2000; Jürgens, 2004; Jürgens and Krzywdzinski, 2008; Ludger and Dehnen, 2009; Lung, 2000; Mordue and Sweeney, 2020; Pavlínek, 2014, 2018, 2022). Europe's integrated periphery is characterised by a high degree of dependence on foreign capital, with foreign investors controlling key producers and suppliers [Drahokoupil et al., (2019), pp.5–6]. The share of European vehicle production in the integrated periphery increased from 7% in 1993 to 21% in 2007 [Brincks et al., (2016), p.134].

3.2 Europe's emerging BEV production geography

The transition away from ICE vehicles is well underway in Europe. "Electrification … is the most disruptive current technological trend shaping the future the automotive industry" [Novaresio and Patrucco, (2022), p.451; Wittmann, 2017]. "The electric vehicle (EV) transition [in Europe] will be a rough and bumpy one" [Hancké and Mathei, (2022), p.2]. The European Union is playing a central role in the transition and has been judged to have abandoned a position of neutrality regarding powertrain technology (Pardi, 2021). "It is now clear that carmakers will need to increase the sales of electric vehicles (EVs) to comply with the 2021 and 2025 CO_2 targets, or face annual penalties …." [Pardi, (2021), p.163]. The question of interest for this paper is how that will impact the industry's production footprint.

By way of reference, in North America, the industry footprint appears to be relatively unchanged by the BEV transition. With a few exceptions, BEVs are being assembled in North America in existing assembly plants converted from ICE vehicle production, rather than in newly constructed greenfield plants (Klier and Rubenstein, 2022a). Although several companies have been established specifically to produce BEVs, to date Tesla is the only start-up producing BEVs in Europe or North America to achieve a significant scale of BEV assembly. Assemblers and suppliers are primarily incumbent companies [Russo et al., (2022), p.153]. Most battery cell plants in North America have been built in greenfield locations rather than installed in buildings previously used for other purposes. However, as is the case with ICE engine plants, battery cell plants are located relatively close to final assembly plants (Klier and Rubenstein, 2022a).

In Europe, the emerging industry footprint is less clear-cut than in North America. For example, Hancké and Mathei (2022, pp.29–30) suggest that "government support and union strength has kept much of the [BEV] production in core countries…." Among Europe's core countries, Germany seems positioned to do well in the BEV transition, whereas France and Italy are not. "Both countries [France and Italy] are behind the electrification curve and their automotive industries are unlikely to come through the EV transition with flying colours…. The French and Italian car industries are set to receive another big blow" [Hancké and Mathei, (2022), p.36].

Regarding the role of the integrated periphery, Pavlínek (2023) suggests that the transformation towards electrification is "unlikely to lead to dramatic changes in the development model of the automotive industry … in the integrated periphery.… The basic features of the integrated periphery, highlighted by Pavlínek (2018, 2020) are likely to endure" [Pavlínek, (2023), p.234]. However, Pavlínek expects the transition towards electrification to be slower in the integrated periphery. He forecasts ICE vehicles to continue to be produced in the integrated periphery for more years than in the core. Reasons cited by Pavlínek include lower production costs, an inventory of modernised factories, a lack of demand for BEVs in that subarea, and a continuing preference for ICE vehicles in the integrated periphery [Pavlínek, (2023), p.233]. Drahokoupil et al. (2019, p.6) suggest that Europe's integrated periphery may benefit from the transition to BEV vehicles through growth in ICE vehicle assembly in the short and mid-term.

An additional element to consider in the emerging geography of BEV production is the degree of vertical integration between final assembly and battery production. "[T]he battery is the most important new module in the electric power train. It has the highest share of value added in an electric vehicle and influences the performance parameters of the vehicle considerably" [Huth et al., (2013), p.76]. The battery value chain consists of two major steps: battery cell manufacturing and battery pack manufacturing (Coffin, 2021; Coffin and Horowitz, 2018; Diaz, 2020; Horowitz et al., 2021). Cell manufacturing accounts for an estimated 65% of a battery's total value added [Huth et al., (2013), p.79].

Huth et al. (2013, pp.82–83) identify four different vertical integration strategies for the battery value chain:

- Full Integrators are active along the whole value chain from cell manufacturing to packaging to control costs and performance of the batteries. To build up the necessary competences these firms have founded joint ventures with companies from the electrical and chemical industries.
- Waiting integrators engage in joint ventures to manufacture battery cells. However, they also source battery packs from suppliers to retain multiple sourcing options.
- Packagers source battery cells from suppliers and integrate them in-house to battery packs. They often enter development partnerships with other OEMs to share relevant competences.
- Purchasers are not yet active in the battery value chain. They source complete battery packs from suppliers.

Eddy et al. (2019) suggest that Europe's carmakers are focusing on the packagers and purchasers strategies, because they do not seem particularly eager to get involved in battery cell manufacturing themselves. First, it is difficult to find the right chemistry, set up the production process, and get other components in place to produce battery cells. This kind of knowledge does not reflect the core competencies of a car OEM. Instead, European automakers typically see value in the packaging of cells into modules and battery packs. Second, producing batteries in-house or switching to a wider base of suppliers – perhaps even European suppliers – often presents risks: namely, that individual suppliers cannot secure enough raw materials at low-enough prices to support the required production [Eddy et al., (2019), p.4].

4 Data

This paper relies primarily on proprietary data acquired from S&P Global Mobility (formerly the automotive team at IHS Markit). S&P Global Mobility data provide information at a much more detailed level than is available from government or United Nations data, which utilise the harmonised tariff schedule (HTS) classification.

We focus in our study on assembly plants that produced at least 50,000 light vehicles in 2022 or were forecast by S&P Global Mobility to do so in 2023. A total of 80 assembly plants met this minimum size criterion.[4] We excluded from our study 30 final assembly plants that are designed to produce only a small number of vehicles; mean production in 2022 at the 30 excluded assembly plants was 5,484 vehicles.

The countries included in the assembly plant data are the 17 vehicle-producing countries in Europe as of 2022. They can be grouped into the three subareas defined in Section 3: core (France, Germany, and Italy), semi-periphery (Austria, Belgium, Finland, the Netherlands, Portugal, Spain, Sweden, and the UK), and integrated periphery (Czechia, Hungary, Poland, Romania, Slovakia, and Slovenia).

The data include the number of vehicles for all models produced at each final assembly plant in Europe in 2021 and 2022, as well as a forecast for 2023. For each vehicle model, the data identify the sources of the powertrain, including location and identity of the supplier, as well as the volume of the powertrain products supplied to each final assembly plant. Note that most final assembly plants are receiving powertrains from more than one location.

Especially important for this study, the data distinguish the volume of each type of powertrain supplied to each final assembly plant. As a result, we can identify the volume of each of the following powertrains shipped to each final assembly plant:

- BEV
- plug-in hybrid electric vehicle (PHEV)
- fuel cell electric vehicle (FCEV)
- ICE vehicle
- hybrid electric vehicle (HEV).

For BEVs, the data show the location of production and the producer for both battery cells and packs.

The data at our disposal include all powertrains sourced by assembly plants in Europe regardless of where they were produced. That enables us to identify linkages between powertrain and assembly operations. Note that our data do not include the number of engines and batteries produced in Europe for export to the rest of the world. Thus, for example, we know the number of engines and batteries imported to Europe from Asia and North America, but we do not know the number exported out of Europe.

5 Distribution of vehicle production

The 80 assembly plants included in our study produced a total of 13,181,979 light vehicles in 2022. In 2022, 27 of the 80 assembly plants produced fewer than 100,000 vehicles, 27 produced between 100,000 and 200,000 vehicles, and 26 produced more than 200,000 vehicles. The mean assembly plant output in 2022 was 164,775 vehicles.

5.1 Distribution of vehicle production by powertrain

In 2022, Europe's light vehicle assembly plants produced approximately 8.0 million ICE vehicles, 2.9 million HEVs, 1.3 million BEVs, and 1.0 million PHEVs (Table 1). In addition, 188 FCEVs were assembled in Europe in 2022. ICE vehicles accounted for 60% of total output, HEVs for 22%, BEVs for 10%, and PHEVs for 8%.

Table 1 Light vehicle output by powertrain, 2022

	ICE	*HEV*	*BEV*	*PHEV*	*FCEV*	*Total*
Units	7,960,801	2,898,845	1,336,839	985,276	188	13,181,979
Share	60.4%	22.0%	10.1%	7.5%	0.0%	

Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

ICE vehicles were produced at 77 of the 80 assembly plants, HEVs and PHEVs at 41 plants each, and BEVs at 38 plants. The fact that these figures total well over 80 is a reflection of the transitional nature of the industry. Only 11 of the 80 plants assembled just one of the four principal types of powertrain; eight assembled only ICE vehicles, and three assembled only BEVs. Two types of powertrains were assembled at 34 of the 80 plants; remarkably, 25 of these 34 plants assembled one of the two electric EV powertrains (BEV or PHEV) and one of the two petrol vehicle powertrains (ICE or HEV). Three of the four powertrains were assembled at 22 of the 80 plants, and all four powertrains were assembled at 13 of the plants.[5]

Note that, consistent with the transitional nature of the industry, mean assembly plant output for each of the powertrains was relatively low in 2022 compared with plant capacity and historical patterns: only 103,387 units for ICE vehicles, 70,704 for HEVs, 35,180 for BEVs, and 24,031 for PHEVs. By comparison, mean assembly plant output was 240,519 vehicles in 2016, compared with only 164,775 in 2022 (Klier and Rubenstein, 2021).

5.2 Distribution of vehicle production by subarea and powertrain

Production can be allocated among Europe's three geographic subareas of core, semi-periphery, and integrated periphery. In 2022, 5.6 million light vehicles were assembled in the core, 4.0 million in the semi-periphery, and 3.6 million in the integrated periphery.

During the 21st century, assembly operations increased in the integrated periphery, from 1.4 million vehicles in 2000 to 3.6 million vehicles in 2022 (Table 2). On the other hand, between 2000 and 2022 production declined from 9.7 million vehicles to 5.6 million vehicles in the core and from 6.4 million vehicles to 4.0 million vehicles in the semi-periphery. However, between 2016 and 2022 light vehicle production declined in all three subareas, from 8.8 million vehicles to 5.6 million vehicles in the core, from 5.4 million vehicles to 4.0 million vehicles in the semi-periphery, and from 3.8 million vehicles to 3.6 million vehicles in the integrated periphery.

Table 2 Light vehicle production by subarea

Production [million vehicles]	*2000*	*2016*	*2022*
Core	9.7	8.8	5.6
Semi-periphery	6.4	5.4	4.0
Integrated periphery	1.4	3.8	3.6
Total production	*17.5*	*18.0*	*13.2*

Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

The share of Europe light vehicle production in the integrated periphery increased substantially, from 8% in 2000 to 22% in 2016 and 27% in 2022. Meanwhile, the share of production in the core declined from 56% in 2000 to 49% in 2016 and 43% in 2022. The share in the semi-periphery declined from 36% in 2000 to 29% in 2016 and to 30% in 2022 (Table 3).

When we disaggregate total production among the four principal powertrain types, sharp variations appear in the output mix within the three subareas. BEV production was clustered in the core in 2022. Assembly plants in the core produced 806,840 BEVs in 2022, compared with only 216,559 in the integrated periphery and 313,400 in the semi-periphery (Table 4). Thus, in 2022 the core accounted for 60% of Europe's BEV production, compared with only 43% for all vehicle production. Figure 1 shows that

BEVs were assembled in 2022 at 22 plants in the core, nine plants in the semi-periphery, and seven in the integrated periphery.

Table 3 Share of light vehicle output by subarea

Production share [%]	*2000*	*2016*	*2022*
Core	56	49	43
Semi-periphery	36	29	30
Integrated periphery	8	22	27
Total production	*17,464,064*	*18,038,912*	*13,181,979*

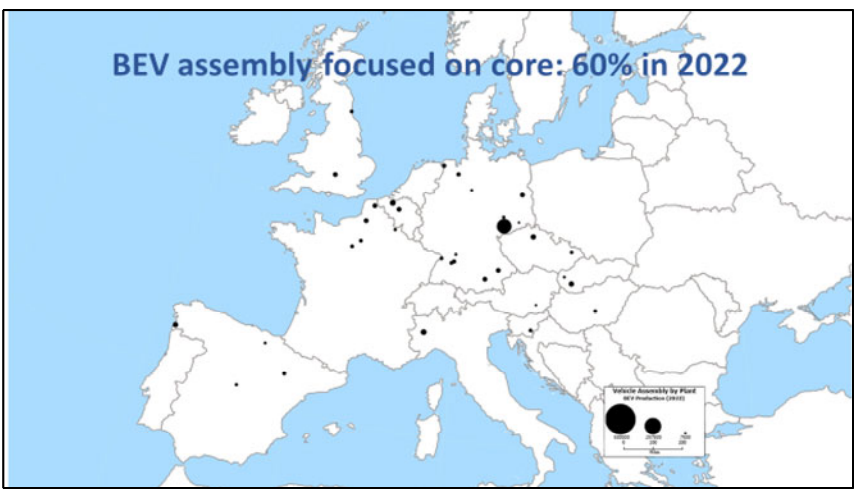
Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

Table 4 BEV output and share of production by subarea, 2022

	All vehicles			*BEVs*		
	No. of vehicles	*Share [%]*	*No. of plants*	*No. of vehicles*	*Share [%]*	*No. of plants*
Core	5,627,383	42.7	39	806,840	60.4	22
Semi-periphery	3,971,304	30.1	23	313,400	23.4	9
Integrated periphery	3,583,292	27.2	18	216,599	16.2	7
Total	*13,181,979*	*100.0*	*80*	*1,336,839*	*100.0*	*38*

Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

Figure 1 BEV assembly plants by volume, 2022 (see online version for colours)



Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

Note that production volumes were relatively low at most of the 38 plants producing BEVs in 2022. The notable exception was VW's Mosel plant in Zwickau, Germany, which produced around 218,000 BEVs in 2022, accounting for 16% of all BEVs assembled in Europe that year.

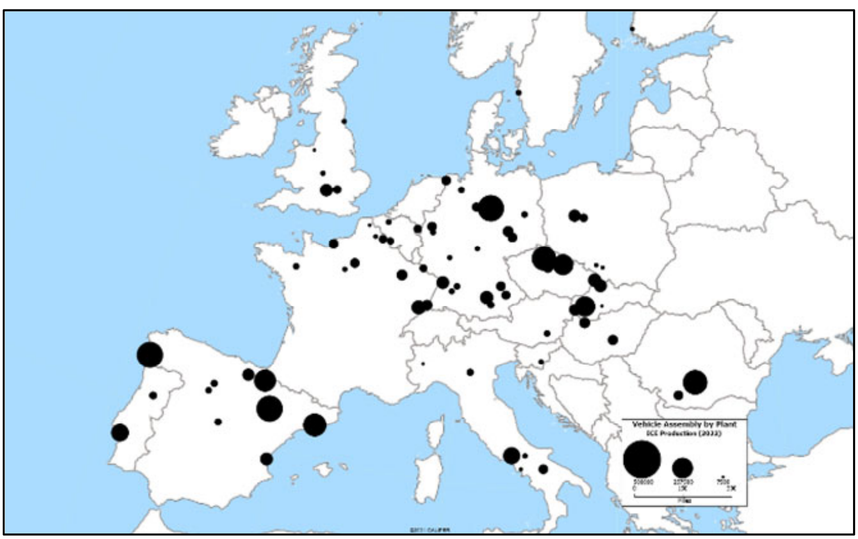
All but one of the 38 assembly plants producing BEVs in 2022 were existing facilities adapted for BEV production. The sole exception was Tesla's assembly plant in Gruenheide, Germany. BEVs accounted for 100% of production in 2022 at two existing assembly plants that VW had converted to BEV production in Zwickau, Germany, and Brussels, Belgium. BEVs were assembled in 2022 alongside other powertrain types at eight plants by Stellantis, at six plants each by Mercedes-Benz and VW, at five plants by BMW, at five plants by Renault, and at one plant each by Geely, Hyundai, Iveco, Magna-Steyr, and Nissan.

Table 5 ICE output and share of production by subarea, 2022

	Volume	*Share [%]*	*# of plants*
Core	3,114,316	39.1	37
Semi-periphery	2,543,357	31.9	22
Integrated periphery	2,303,128	28.9	18
Total	7,960,801	100.0	77

Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

Figure 2 ICE assembly plants by volume, 2022 (see online version for colours)



Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

The distribution of ICE production among the three subareas varied sharply from that of BEVs. Assembly plants in the core accounted for only 39% of ICE vehicle production in Europe in 2022, compared with 29% in the integrated periphery and 32% in the semi-periphery (Table 5). The share of Europe's ICE vehicle production in the core declined sharply in six years, from 49% in 2016 to 39% in 2022, whereas the share in the integrated periphery increased during the six years from 22% to 29% (see Tables 3 and 5).

ICE vehicle production within Europe is clustered in two principal areas (Figure 2). One area runs in a northwest-southeast corridor between Germany (in the core subarea) and Czechia and Slovakia (in the integrated periphery). The second principal area is in northeastern Spain (in the semi-periphery).

Each of Europe's three subareas displays a distinctive share of production by powertrain type. The core has a relatively high share of BEV production and a relatively low share of ICE vehicle production compared to the overall share of production by subareas. On the other hand, the integrated periphery has relatively small shares of the two electric powertrains (BEV and PHEV). The semi-periphery has a smaller share of BEV and HEV production but a higher share of PHEV production than the overall distribution of output. Table 6 summarises the share of production among the three subareas for all four types of powertrains in 2022.

Table 6 Share of production by subarea and powertrain, 2022

Subarea	*Total production [million vehicles]*	*Share of production [%]*			
		ICE	*HEV*	*BEV*	*PHEV*
Core	5.6	39	44	60	43
Semi-periphery	4.0	32	25	23	39
Integrated periphery	3.6	29	30	16	19
Total	*13.2*	*100*	*100*	*100*	*100*

Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

6 Comparing co-location and economies of scale for final assembly and powertrain plants

Previous studies have demonstrated that ICE engine and vehicle assembly operations have a high degree of co-location. That is, most ICE engine plants are located near final assembly plants. In addition, ICE vehicle assembly and engine production have different economies of scale. As a result, ICE engine plants are typically fewer in number and produce substantially more units than is the case with ICE assembly plants.

In this study, we find that BEV production also demonstrates co-location and varying economies of scale between vehicle assembly and battery plants. However, the patterns are not identical with those prevailing for ICE vehicle production.

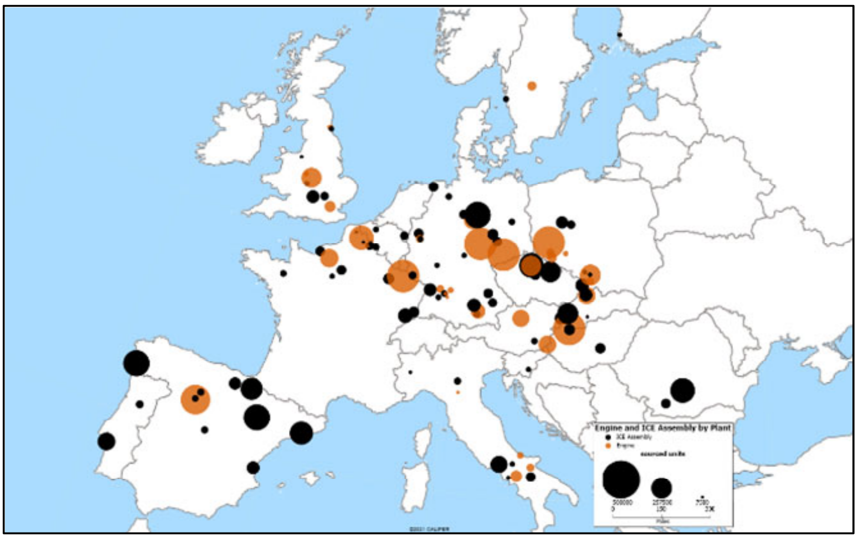
6.1 Co-location and economies of scale for ICE production

ICE production has declined sharply in Europe in recent years, but the high degree of co-location between ICE engine and ICE final assembly plants within Europe persists in 2022 (Figure 3). Note that Figure 3 shows only final assembly and engine production for ICE vehicles. Production of engines for HEVs and PHEVs is not included in this map.

Previous studies have also shown that economies of scale vary between ICE vehicle assembly plants and engine plants. For example, Klier and Rubenstein (2021) found that in 2016 Europe had 75 final assembly plants and 40 engine plants. Mean output in 2016 was 241,000 units in final assembly plants and 522,000 in engine plants.

The 2022 data for this article show similar variations. As production of ICE vehicles and engines declines in Europe, the substantial variation in economies of scale persists between final assembly plants and engine plants. In 2022, mean output was 103,387 ICE vehicles at final assembly plants and 194,951 ICE engines at Europe's 40 engine plants.

Figure 3 Location of ICE vehicle assembly plants and engine plants, 2022 (see online version for colours)



Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

As ICE vehicle production declined, European OEMs maintained roughly the same number of final assembly plants and engine plants. Between 2016 and 2022, the number of final assembly plants producing ICE vehicles increased slightly, from 36 to 37 in the core and from 16 to 18 in the integrated periphery; the number in the semi-periphery has declined from 23 to 22.

Table 7 ICE assembly and engine number of plants and production share by subarea, 2022

Subarea	*ICE assembly*		*ICE engines*	
	No. of plants	*Share [%]*	*No. of plants*	*Share [%]*
Core	37	39.1	19	45.5
Semi-periphery	22	31.9	9	14.4
Integrated periphery	18	28.9	12	37.7
Imported	N/A	N/A	N/A	2.4
Mean production per plant		*103,387*		*194,951*

Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

Europe's overall number of ICE engine plants remained unchanged between 2016 and 2022. The number declined from 12 to 9 in the semi-periphery, increased from 9 to 12 in the integrated periphery, and remained at 19 in the core. Note that the number of plants has remained about the same despite the sharp decline in ICE vehicle production in part because ICE vehicle assembly plants may also be producing HEVs, PHEVs, and BEVs. And engine plants may also be supplying ICE engines for HEVs and PHEVs.

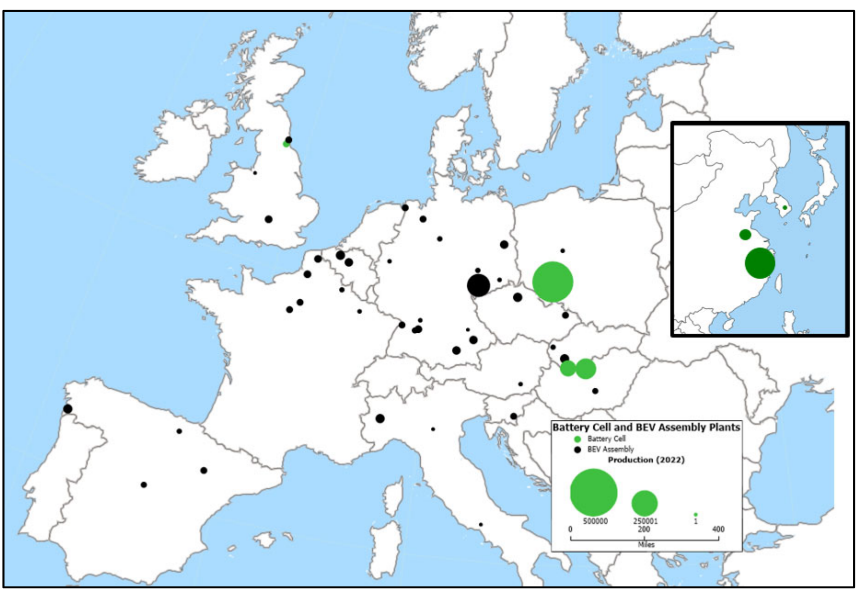
The core and integrated periphery both had higher shares of ICE engine production in 2022 compared with ICE vehicle assembly; plants in the semi-periphery feature a much lower share of Europe's engine production compared with ICE vehicle assembly production (Table 7).

6.2 Co-location and economies of scale for battery cell production

Batteries are produced at two types of factories: battery cell plants and battery pack plants.

- Cell plants manufacture individual batteries, which are composed of an anode, a cathode, and an electrolyte, as well as a separator and a casing.
- Pack plants bring together many individual battery cells, along with various connectors, circuits, and power management systems. Cells may be grouped first into modules, several of which are then brought together in a pack.

Figure 4 Location of battery cell plants supplying Europe BEV assembly plants, 2022 (see online version for colours)



Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

Our data permit us to identify the location of the manufacturer, the sourcing volume for every battery cell and battery pack, as well as the composition of the cells. We find that the geography of cell production currently differs significantly from that of pack production in Europe.

All battery cells installed in BEVs in Europe in 2022 were manufactured by independent suppliers rather than by OEMs. The 38 assembly plants included in our study that produced BEVs in 2022 received battery cells from a remarkably small number of sources (Table 8). Just four factories supplied 88% of the cells installed in the 1,336,839 million BEVs assembled in Europe in 2022: 36% came from LG Energy Solution's cell plant in Wrocław, Poland, 28% from CATL (Contemporary Amperex Technology Co., Limited) headquarters in Ningde, China, 14% from Samsung SDI's cell plant in Goed, Hungary, and 10% from SK Innovation's cell plant in Komárom, Hungary. Thus, the three largest battery cell plants in operation in Europe in 2022 were located in the integrated periphery, specifically two in Hungary and one in Poland (Figure 4). The only other battery cell plant operating in Europe in 2022 was located in the UK.

Table 8 Source of battery cells in BEVs assembled in Europe, 2022

Location	*Cell manufacturer*	*Share [%]*
Wrocław, Poland	LG Energy Solution	36.2
Ningde, China	CATL	27.8
Goed, Hungary	Samsung SDI	14.3
Komárom, Hungary	SK Innovation	10.4
Other China locations	Various	6.6
Sunderland, UK	Envision AESC	2.3
Other countries	Various	2.4
Total		*1,336,839*

Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

6.3 Co-location and economies of scale for battery pack production

While only four plants supplied nearly 90% of the cells used at Europe's 38 BEV assembly plants, packs came from 27 plants. Furthermore, whereas only 59% of BEVs were assembled with cells manufactured in Europe, 98% of the packs were manufactured in Europe.

The type of manufacturer also varied between cell and pack producers. Independent suppliers manufactured 100% of the battery cells used in Europe's BEV assembly plants, compared with only 10% of the battery packs. While OEMs outsourced all of their cells, they made 90% of the packs in-house (Table 9).

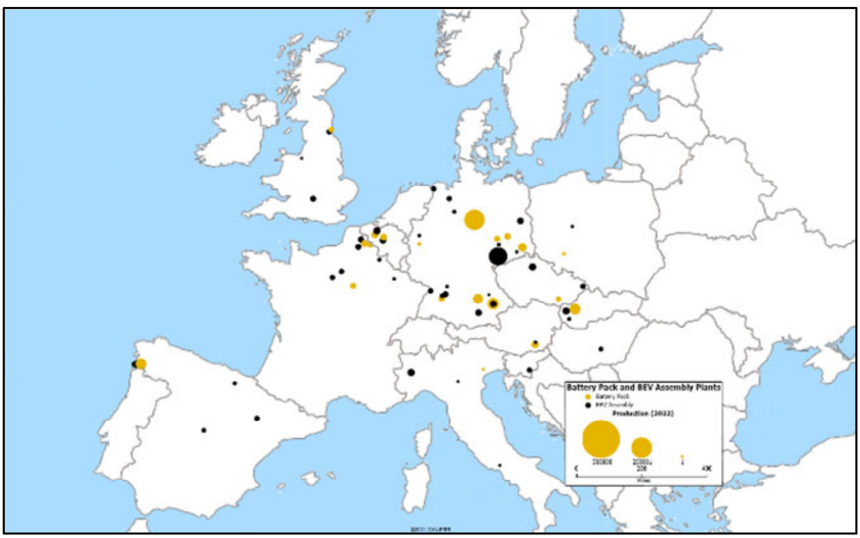
Most of the packs made by OEMs were produced inside or near a final assembly plant. Therefore, a map of pack plants shows a distribution nearly identical to the distribution of BEV final assembly plants (Figure 5). The reason is that most packs are designed to be integrated into the chassis, and most chassis are manufactured inside final assembly plants. The principal exception in 2022 was VW, which put together a large number of packs at its Braunschweig, Germany, plant that produces axles and steering systems but does not include final assembly operations.

Table 9 Source of battery packs in BEVs assembled in Europe, 2022

	Share [%]
Made in-house by OEM	90.1
At or adjacent to a final assembly plant	62.8
At another OEM plant	27.3
Outsourced to independent supplier	9.9
Made in Europe	8.0
Made outside Europe	1.8
Total production	*1,336,839*

Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

Figure 5 Location of battery pack plants supplying Europe BEV assembly plants, 2022 (see online version for colours)



Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

Table 10 Share of production among subareas for BEV assembly, pack, and cell production, 2022

Share of production	*BEV production*	*% Assembly*	*% Pack*	*% Cell*
Core	806,840	60.4%	61.8%	0.0%
Semi-periphery	216,599	23.4%	23.3%	2.3%
Integrated periphery	313,400	16.2%	11.0%	58.9%
Imported	N.A.	N.A.	2.0%	38.8%
Total	*1,336,839*	*100%*	*100%*	*100%*

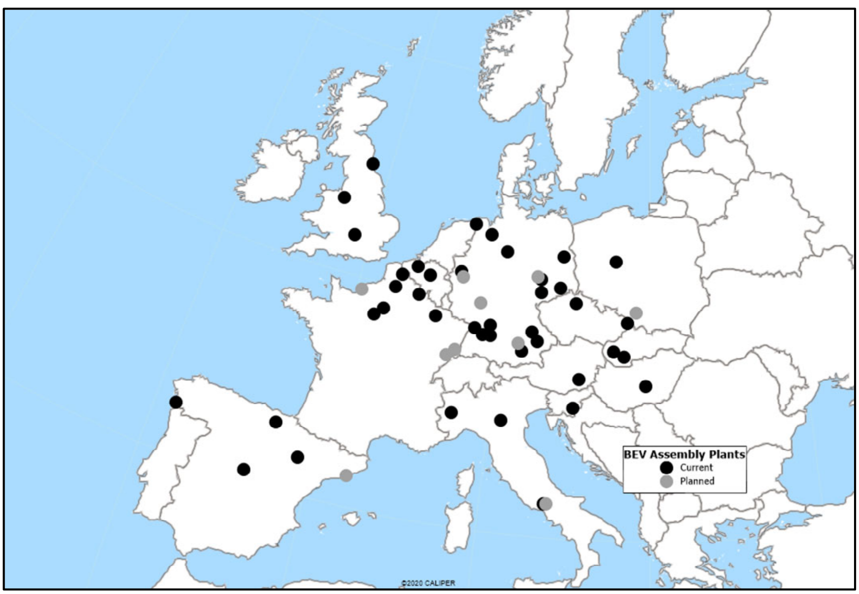
Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023

Given the almost 100% co-location between pack plants and final assembly plants, the distribution of production among the three subareas is nearly identical for the two types of factories (Table 10). The core had 60% of final assembly output and 62% of pack production, the semi-periphery had 23% of both final assembly and pack production, and the integrated periphery had 16% of final assembly output and 11% of pack production. Cell production is the outlier, as almost all cells are either produced in the integrated periphery or imported from Asia.

6.4 Emerging patterns

In this section, we look ahead regarding emerging patterns in BEV and battery cell production in Europe. Our principal data source (S&P Global) identified nine assembly plants in Europe that would begin assembly of BEVs during 2023. These nine were in addition to the 38 that were already assembling BEVs during 2022. Eight of the nine additional BEV assembly plants were in the core, and one was in the integrated periphery (Figure 6). As a result, the number of plants assembling BEVs in 2023 was forecast to rise to 30 in the core, nine in the semi-periphery, and eight in the integrated periphery.

Figure 6 Location of BEV assembly plants, 2023 forecast (see online version for colours)



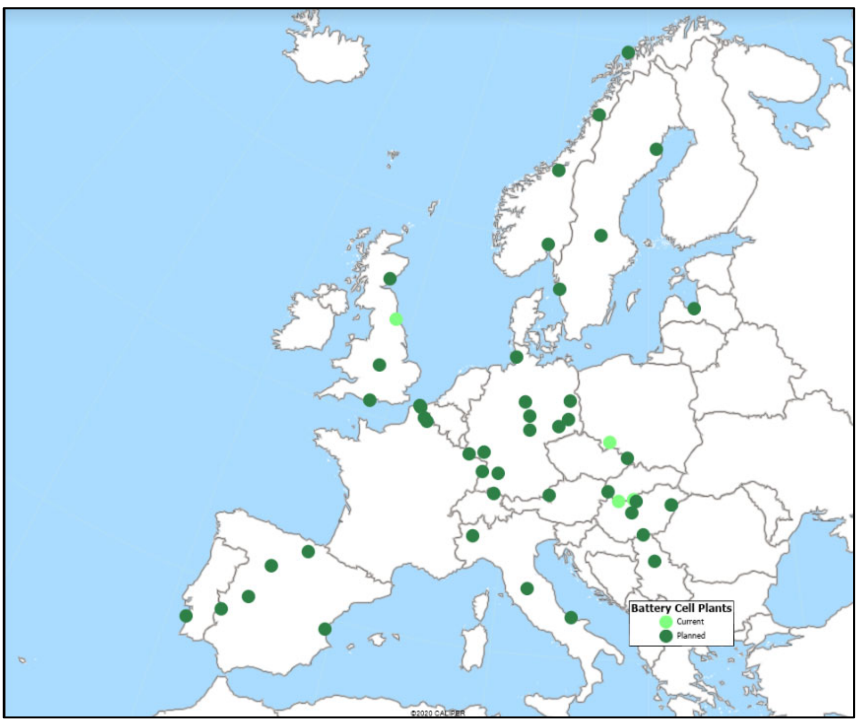
Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023; Automotive News

Thus, the clustering of BEV assembly operations in the core is forecast by S&P Global to increase rather than diminish in the immediate future. This represents a reversal of the geography that emerged in the first years of the 21st century, in which the integrated periphery has played an increasingly important role in ICE vehicle assembly operations within Europe (see the trend shown in Table 3).

The number of battery cell plants is also anticipated to increase sharply in Europe in the years ahead. S&P Global forecast that the number of cell plants in Europe would increase in 2023 from four to seven. The three additional plants included two in the core and one in the integrated periphery. SK Innovation was expected to open a second cell plant in Hungary in 2023, and Automotive Cells and CATL were forecast to open their first European cell plants, in Italy and Germany, respectively. In addition, 42 cell plants under construction or active development were anticipated to open by 2030, based on Heimes (2022), supplemented by articles in *Automotive News*, *Electrive*, and *Reuters* (Figure 7).

If all battery cell plants shown in Figure 7 start producing by 2030, Europe would have a total of 49 cell plants by the beginning of the next decade. Their locations would be distributed among the three subareas as follows: 19 in the core, 18 in the semi-periphery, and 12 in the integrated periphery, corresponding to 39%, 27%, and 24% of plants, respectively. Remarkably, these 49 plants would be operated by 35 different companies.

Figure 7 Location of battery cell plants, 2023–2030 forecast (see online version for colours)



Source: Authors' calculations based on data from S&P Global Mobility light vehicle production as of February 2023; Heimes (2022)

7 Discussion

The emerging geography of BEV production in Europe appears relatively straightforward for both assembly plants and battery pack plants, at least for the next several years. The distribution of battery cell plants within Europe in the next few years is less settled.

At the scale of Europe as a whole, the geography of final assembly has not changed. Most vehicles sold in Europe are assembled in Europe, regardless of whether they are ICE or BEV. Economic geography factors of agglomeration economics and economies of scale explain this pattern.

However, at the scale of subareas within Europe, the geography of final assembly is changing with the transition towards BEVs. Whereas assembly plants in the integrated periphery have been growing, producing 29% of Europe's total ICE vehicles in 2022, most of Europe's BEVs in 2022 were assembled in the core. The core-periphery literature suggests that innovations (such as BEVs) are more likely to be produced in the core, whereas generic and routinised operations (such as ICE technology) are more likely to be performed in the periphery. The pre-eminence of the core in BEV assembly is consistent with increasing regional specialisation within transnational production networks. New technologies, such as the conversion from ICE vehicle to BEV production, "increase the specialisation of core regions in capital-intensive production, skill-intensive, high-value-added activities, and strategic functions" [Pavlínek, (2022), p.65].

Therefore, for the immediate future, the core appears likely to hold a much larger share of Europe's BEV assembly than ICE vehicle assembly. In the long run, though, given that every BEV assembly plant in Europe has been installed in an existing ICE vehicle assembly plant, with one exception (Tesla's newly constructed assembly plant in Gruenheide, Germany), the geography of BEV assembly may ultimately resemble the current geography of ICE vehicle assembly, with the core, semi-periphery, and integrated periphery accounting for roughly equal shares of production.

The geography of pack production also appears to be relatively straightforward. The pack is most comparable to the chassis or platform of a vehicle, rather than to the engine [Graham, (2021), p.262]. The ICE vehicle chassis or platform is typically manufactured in or near a final assembly plant, a pattern that appears to be continuing with BEV assembly. Thus, with most BEVs now assembled in the core, so too most battery packs are now assembled in the core.

The geography of cell production, however, appears subject to competing influences. In 2022, Europe's three largest battery cell factories were all located in the integrated periphery. Four cell plants–three in Europe's integrated periphery and one plant in China–supplied 87% of cells used in Europe's BEV assembly plants in 2022. Production in the integrated periphery is typically characterised by production of relatively simple and generic components [Pavlínek, (2022), p.60; (2020), p.513]. The initial clustering of Europe's cell plants in the integrated periphery suggests that cell production might be an example of a generic component suitable for production in large volumes in relatively few plants with large economies of scale.

Looking towards the medium-term future, the number of cell plants in Europe is forecast to increase substantially. A total of 49 cell plants are anticipated to be operating in Europe by 2030. The total number of cells forecast to be produced in these plants is roughly comparable to the number needed in BEV vehicles forecast to be sold in Europe – and therefore presumably assembled in Europe – over the next few years. Of the cell plants currently anticipated by the end of the decade, around one-fourth will be in the integrated periphery. The remainder would be about equally divided between the core and semi-periphery.

So, what are the geographic factors explaining what is happening with cell production? One possibility is that the cell becomes a generic part and would therefore likely be manufactured in the integrated periphery or overseas by a low-cost high-volume supplier. The first cell plants in Europe are in fact located in the integrated periphery. Alternatively, cell production – like BEV assembly – involves numerous innovations, and therefore most cell plants would locate in the core. The cell might play a key role in an OEM's development and marketing of a unique product, much as the engine does now. At the moment, OEMs lack the expertise to manufacture cells. In the years ahead, though, OEMs might make cell production part of their core competencies and identification of their distinctive products.

Furthermore, is the location of cell plants currently under development in Europe a function of decisions by OEMs and independent suppliers to cluster innovative production functions in the core? Or is it a function of policies by some European countries to subsidise domestic initiatives in an innovative market and minimise dependency on battery companies based in Asia? Consequently, Europe's initial geography of BEV production – final assembly and pack plant mostly in the core and cell production mostly in the integrated periphery – may well change going forward.

References

Brincks, C., Domański, B., Klier, T. and Rubenstein, J. (2018) 'Integrated peripheral markets in the auto industries of Europe and North America', *International Journal of Automotive Technology and Management*, Vol. 18, No. 1, pp.1–28.

Brincks, C., Klier, T. and Rubenstein, J. (2016) 'The role of national champions in the evolving footprint of vehicle production in Europe-1990–2013', *International Journal of Automotive Technology and Management*, Vol. 16, No. 2, pp.130–146.

Center for Automotive Research (2017) 'Automotive product development cycles and the need for balance with the regulatory environment', 20 September [online] https://www.cargroup.org/automotive-product-development-cycles-and-the-need-for-balancewith-the-regulatory-environment/ (accessed 26 May 2023).

Chanaron, J. (2004) 'Relationships between the core and the periphery of the European automotive system', *International Journal of Automotive Technology and Management*, Vol. 4, Nos. 2–3, pp.198–222.

Coffin, D. (2021) *The Forgotten Middle: Manufactured Inputs for Electric Vehicle (EV) Batteries*, United States International Trade Commission, Washington.

Coffin, D. and Horowitz, J. (2018) *The Supply Chain for Electric Vehicle Batteries*, United States International Trade Commission, Washington.

Davis, J. (2013) 'Casting, forming, and forging', *Gear Solutions*, Vol. 11, No. 5, pp.24–35.

Diaz, M.N. (2020) *Electric Vehicles: A Primer on Technology and Selected Policy Issues*, Congressional Research Service, Washington.

Domański, B. and Lung, Y. (2009) 'The changing face of the European periphery in the automotive industry', *European Urban and Regional Studies*, Vol. 16, No. 1, pp.5–10.

Drahokoupil, J., Guga, Ștefan, Martišková, M., Pícl, M. and Pogátsa, Z. (2019) *The Future of Employment in the Car Sector: Four Country Perspectives from Central and Eastern Europe*, Friedrich Ebert Stiftung, Praha.

Eddy, J., Pfeiffer, A. and van de Staaij, J. (2019) *Recharging Economies: The EV-Battery Manufacturing Outlook for Europe*, McKinsey & Co. [online] https://www.mckinsey.com/~/media/McKinsey/Industries/Oil%20and%20Gas/Our%20Insights/Recharging%20economies%20The%20EV%20battery%20manufacturing%20outlook%20for%20Europe/Recharging-economies-The-EV-battery-manufacturing-outlook-for-Europe-vF.pdf (accessed 16 January 2024).

Flink, J. (1990) *The Automobile Age*, MIT Press, Cambridge.

Glaeser, E. (Ed.) (2010) *Agglomeration Economics*, University of Chicago Press, Chicago [online] https://www.nber.org/books-and-chapters/agglomeration-economics (accessed 26 May 2023).

Graham, J. (2021) *The Global Rise of the Modern Plug-In Electric Vehicle*, Edward Elgar, Cheltenham and Northampton.

Gregory, D., Johnston, R., Pratt, G., Watts, M. and Whatmore, S. (Eds.) (2009) *Dictionary of Human Geography*, 5th ed., Wiley-Blackwell, Chichester.

Hancké, B, and Mathei, L. (2022) *The Political Economy of Electrification in the European Car Industry*, European Climate Foundation [online] http://eprints.lse.ac.uk/108303/1/europpblog_2020_12_16_the_political_economy_of_electric.pdf (accessed 26 May 2023).

Head, K. and Mayer, T. (2019) 'Brands in motion: how frictions shape multinational production', *American Economic Review*, Vol. 109, No. 9, pp.3073–3124.

Heimes, H. (Ed.) (2022) *Battery Atlas 2022: Shaping the European Lithium-Ion Battery Industry*, Aachen University [online] https://www.pem.rwth-aachen.de/global/show_document.asp?id=aaaaaaaabpjuwfj (accessed 18 May 2023).

Henry, I. (2017) 'Around the block', *Automotive Manufacturing Solutions*, 16 March [online] https://automotivemanufacturingsolutions.com/focus/around-the-block (accessed 1 April 2019).

Horowitz, J., Coffin, D. and Taylor, B. (2021) *Supply Chain for EV Batteries: 2020 Trade and Value-Added Update*, United States International Trade Commission, Washington.

Humphrey, J. and Oeter, A. (2000) 'Motor industry policies in emerging markets: Globalisation and the promotion of domestic industry', in Humphrey, J., Lecler, Y. and Sergio Salerno, M. (Eds.): *Global Strategies and Local Realities: The Auto Industry in Emerging Markets*, pp.42–71, Palgrave Macmillan, Basingstoke.

Husan, R. (1997) 'The continuing importance of economies of scale in the automotive industry', *European Business Review*, Vol. 97, No. 1, pp.38–42.

Huth, C., Wittek, K. and Spengler, T.S. (2013) 'OEM strategies for vertical integration in the battery value chain', *International Journal of Automotive Technology and Management*, Vol. 13, No. 1, pp.75–92.

International Energy Agency (IEA) (2021) *Global EV Outlook 2021* [online] https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf (accessed 26 May 2023).

Jürgens, U. (2004) 'Characteristics of the European automotive system: is there a distinctive European approach?', *International Journal of Automotive Technology and Management*, Vol. 4, Nos. 2–3, pp.112–136.

Jürgens, U. and Krzywdzinski, M. (2008) 'Relocation and east-west competition: the case of the European automotive industry', *International Journal of Automotive Technology and Management*, Vol. 8, No. 2, pp.145–169.

Kirsch, D. (2000) *The Electric Vehicle and the Burden of History*, Rutgers University Press, New Brunswick and London.

Klier, T. and Rubenstein, J. (2008) *Who Really Made Your Car? Restructuring and Geographic Change in the Auto Industry*, W.E. Upjohn Institute for Employment Research, Kalamazoo.

Klier, T. and Rubenstein, J. (2015) 'Auto production footprints: comparing Europe and North America', *Economic Perspectives*, Vol. 39, No. 4, pp.101–119.

Klier, T. and Rubenstein, J. (2021) 'ICE age geography: powertrain sourcing in Europe and North America', *International Journal of Automotive Technology and Management*, Vol. 21, No. 4, pp.322–342.

Klier, T. and Rubenstein, J. (2022a) 'North America's rapidly growing electric vehicle market: implications for the geography of automotive production', *Economic Perspectives*, Vol. 46, No. 5, pp.1–27.

Klier, T. and Rubenstein, J. (2022b) 'Trade agreements and the geography of motor vehicle production in North America and Europe', *International Journal of Automotive Technology and Management*, Vol. 22, No. 1, pp.4–28.

Layan, J-B. (2000) 'The integration of peripheral markets: a comparison of Spain and Mexico', in Humphrey, J., Lecler, Y. and Sergio Salerno, M. (Eds.): *Global Strategies and Local Realities: The Auto Industry in Emerging Markets*, pp.122–148, Palgrave Macmillan, Basingstoke.

Ludger, P. and Dehnen, V. (2009) 'Location tendencies of the international automotive industry: 'footless companies going east and south' or 'regionalisation of value chain profiles?', *International Journal of Automotive Technology and Management*, Vol. 9, No. 4, pp.415–437.

Lung, Y. (2000) 'Is the rise of emerging countries as automobile producers an irreversible phenomenon?', in Humphrey, J., Lecler, Y. and Sergio Salerno, M. (Eds.): *Global Strategies and Local Realities: The Auto Industry in Emerging Markets*, pp.16–41, Palgrave Macmillan, Basingstoke.

Lung, Y. (2003) 'The changing geography of the European automobile system', *Groupement de Recherche Economique et Sociales*, Toulouse and Pessac, France.

Lung, Y. (2004) 'The changing geography of the European automobile system', *International Journal of Automotive Technology and Management*, Vol. 4, Nos. 2–3, pp.137–165.

Manello, A. and Calabrese, G. (2015) 'The restructuring of tier 1 automotive suppliers in Europe during the crisis', *International Journal of Automotive Technology and Management*, Vol. 15, No. 1, pp.80–95.

Mordue, G. and Sweeney, B. (2020) 'Neither core nor periphery: the search for competitive advantage in the automotive semi-periphery', *Growth and Change*, Vol. 51, No. 1, pp.34–57.

Novaresio, A. and Patrucco, P.P. (2022) 'Patterns of green innovation in the automotive industry: empirical evidence from OECD countries 1990–2018', *International Journal of Automotive Technology and Management*, Vol. 22, No. 4, pp.450–484.

Pardi, T. (2021) 'Prospects and contradictions of the electrification of the European automotive industry: the role of European Union policy', *International Journal of Automotive Technology and Management*, Vol. 21, No. 3, pp.162–179.

Pavlínek, P. (2014) 'Whose success? The state-foreign capital nexus and the development of the automotive industry in Slovakia', *European Urban and Regional Studies*, Vol. 22, No. 4, pp.1–23.

Pavlínek, P. (2018) 'Global production networks, foreign direct investment, and supplier linkages in the integrated peripheries of the automotive industry', *Economic Geography*, Vol. 94, No. 2, pp.141–165.

Pavlínek, P. (2020) 'Restructuring and internationalization of the European automotive industry', *Journal of Economic Geography*, Vol. 20, No. 2, pp.509–541.

Pavlínek, P. (2022) 'Relative positions of countries in the core-periphery structure of the European automotive industry', *European Urban Regional Studies*, Vol. 29, No. 1, pp.59–84.

Pavlínek, P. (2023) 'The transition to the production of electric vehicles in Czechia and Slovakia', in Galgóczi, B. (Ed.): *On the Way to Electromobility – A Green(er) but More Unequal Future?*, Ch. 6, pp.207–239, European Trade Union Institute (ETUI), Brussels.

Pavlínek, P. and Ženka, J. (2011) 'Upgrading in the automotive industry: firm-level evidence from Central Europe', *Journal of Economic Geography*, Vol. 11, No. 3, pp.559–586.

Rhys, D.G. (1972) *Motor Industry: An Economic Survey*, Butterworths, London.

Rhys, D.G. (2005) 'Competition in the auto sector: the impact of the interface between supply and demand', *International Journal of Automotive Technology and Management*, Vol. 5, No. 3, pp.261–283.

Rubenstein, J. (1992) *The Changing U.S. Auto Industry: A Geographical Analysis*, Routledge, London and New York.

Rubenstein, J. (2001) *Making and Selling Cars*, The Johns Hopkins University Press, Baltimore and London.

Russo, M., Alboni, F., Bonifati, G., Carreto-Sanginés, J. and Pavone, P. (2022) 'Agents and artefacts in the emerging electric vehicle space', *International Journal of Automotive Technology and Management*, Vol. 22, No. 2, pp.150–177.

Truett, L. and Truett, D. (2001) 'The Spanish automotive industry: scale economies and input relationships', *Applied Economics*, Vol. 33, No. 12, pp.1503–1513.

Truett, L. and Truett, D. (2003) 'The Italian automotive industry and economies of scale', *Contemporary Economic Policy*, Vol. 21, No. 3, pp.329–337.

Wakefield, E. (1994) *History of the Electric Automobile*, Society of Automotive Engineers, Warrendale, PA.

Weber, A. (1929) *Alfred Weber's Theory of the Location of Industries*, in Friedrich, C.J. (Trans. and Ed.) University of Chicago Press, Chicago.

Wells, P. and Rawlinson, M. (1994) *The New European Automobile Industry*, Macmillan, Basingstoke.

Wittmann, J. (2017) 'Electrification and digitalization as disruptive trends: new perspectives for the automotive industry?', in Khare, A., Stewart, B. and Schatz, R. (Eds.): *Phantom Ex Machina: Digital Disruption's Role in Business Model Transformation*, pp.137–159, Springer, Berlin.

Womack J., Jones D. and Roos D. (1990) *The Machine That Changed the World*, Rawson, New York.

Wynn-Williams, M. (2009) 'Economies of scale in the auto industry', in *Surfing the Global tide: Automotive Giants and How to Survive Them*, pp.41–71, Palgrave Macmillan, Basingstoke and New York.

Notes

1 The term EV is generally includes both BEV and PHEV (plug-in hybrid vehicle). A PHEV has both an ICE and a battery-powered electric motor. A PHEV battery can be charged by an electric power source, by the engine, or through regenerative braking.

2 The three subareas have also been applied to North America [see Klier and Rubenstein, (2022b), p.7; Mordue and Sweeney, 2020).

3 Pavlínek (2022) further divided countries into stable and unstable core, stable and unstable semi-periphery, and stable and unstable integrated periphery. The countries identified by Pavlínek as stable core are referred to in this article as core. The countries identified by Pavlínek as unstable core and stable semi-periphery are referred to in this article as semi-periphery. The countries identified by Pavlínek as unstable semi-periphery, stable periphery, and unstable periphery are referred to in this article as integrated periphery, with two exceptions. Pavlínek assigned Portugal to stable periphery, but in this article Portugal is included with the semi-periphery. Pavlínek (2022) did not include Serbia, which this article includes with the integrated periphery. Several countries included in Pavlínek's study are not included here, because this article is limited only to countries that currently assemble vehicles.

4 77 assembly plants produced at least 50,000 light vehicles in 2022. Assembly plants in Brussels, Belgium; Eisenach, Germany; and Gliwice, Poland assembled fewer than 50,000 vehicles in 2022, but were forecast by S&P Global to exceed 50,000 in 2023.

5 Two assembly plants in France counted as producing two types of powertrains also produced a total of 188 FCEVs in 2022. Those two plants were the only ones producing FCEVs that year.