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LITHIUM-ION BATTERY GLOBAL PATENT RACE (1990-2019)

CORRIDA GLOBAL DE PATENTE DE BATERIA DE ÍON DE LÍTIO (1990-2019)

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Abstract: Lithium-ion battery (LIB) is a key subject nowadays once CO2 emissions level, energy matrix, zero emission target and electric mobility are priority among governments and companies. The aim of this paper is to analyze LIB patent race, from 1990 to 2019, by country, sectors, and companies, using data from Derwent Innovation Platform, a Clarivate Analytics Group product. Our main results are: i) China and Japan concentrate the main companies, ii) Information and Communication Technology is the main sector in Electric Devices (ED) battery and Automobilistic in Electric Vehices (EV) battery, iii) some companies are in ED and EV, suggesting direct spillovers from ED to EV battery. Other firms are only in ED, others only in EV, iv) Latin American, Africa and Central Asia are out of this patent race. The main conclusion are i) this patent race winners are in Asia nowadays, ii) leading firms in electric devices are not that in vehicle batteries.

Keywords: Electric mobility, Lithium-ion battery, Patent race.

Resumo: A bateria de íons de lítio (LIB) é um assunto fundamental hoje em dia, uma vez que o nível de emissões de CO2, a matriz energética, a meta de emissão zero e a mobilidade elétrica são prioridade entre governos e empresas. O objetivo deste artigo é analisar a corrida de patentes LIB, de 1990 a 2019, por país, setores e empresas, utilizando dados da Derwent Innovation Platform, produto do Clarivate Analytics Group. Nossos principais resultados são: i) China e Japão concentram as principais empresas, ii) Tecnologia da Informação e Comunicação é o principal setor em baterias de Dispositivos Elétricos (ED) e baterias Automobilísticas em Veículos Elétricos (EV), iii) algumas empresas estão em ED e EV, sugerindo repercussões diretas da bateria ED para a bateria EV. Outras empresas estão apenas em ED, outras apenas em EV, iv) América Latina, África e Ásia Central estão fora desta corrida de patentes. A principal conclusão é que i) os vencedores desta corrida de patentes estão hoje na Ásia, ii) as empresas líderes em dispositivos elétricos não são as mesmas em baterias de veículos.

Palavras-Chave: Mobilidade elétrica, Bateria de íons de lítio, Corrida de patentes.

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1 Introduction

CO2 emissions level in general and energy matrix in particular justify zero emission targets and electric mobility policies in many countries, and a lithium-ion battery patent race is a consequence. In fact, increase in Electric Vehicles (EV) production in the last few years puts lithium-ion batteries among top economic issues nowadays as many studies suggest.

According to Global EV Outlook, 2020 edition, in 2010 there were about 17.000 electric cars in the world. It jumped to 7.2 million in 2019, 47% in China. Almost 90% of global electric car sales concentrated in China, Europe and the United States. On the other hand, battery costs have decreased more than 85% since 2010. In this positive scenario, with increased sales and battery cost reduction, the automakers have announced plans to release another 200 new electric car models up to 2025, many of which are in the popular sport utility vehicle market segment.

Based on a set of data about the global Electric Vehicles (EV) market from 2013 to 2020, Li et al. (2021) focus on the 13 countries responsible for 95% of total global EV sales during this period: Austria, Canada, China, France, Germany, Japan, Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, and United States. Also, according to them, China is by far the largest EV market in 2016-2019, accounting for 40%-60% of global sales. In 2020, Europe overtook China and became the largest EV market, with 43% market share. Germany, United Kingdom, France, Norway, Netherlands, and Sweden had substantial growth in EV sales from 2018 to 2020, in spite of relatively low market share for each country. But market shares of EVs in the United States reduced from 47% in 2013 to 10% in 2020.

Nevertheless, it is not only about electrifying cars, but also about transport modes other than cars such as two or three wheelers (2-3-W) and urban buses. Electric micro mobility options increased exponentially since their emergence in 2017, with shared e-scooters and e-bikes, now available in over 600 cities across more than 50 countries. An estimated stock of 350 million electric 2-3-W, the majority of which are in China, make up 25% of all 2-3-W in circulation worldwide. About half a million electric buses are in circulation, most of which are in China (Global EV Outlook, 2020).

In a broad perspective it is important to consider the cost of reducing greenhouse gas emissions and keep in mind that the static options are not necessarily the best in a dynamic perspective, and vice versa (Gillingham, Stock, 2018). Three transition pathways to 2030 may emerge from the current situation of urban mobility, says Marletto (2014): 1) “AUTO-city”, i.e. the reconfiguration of the “individual car” dominant system through the stable integration of producers of batteries; 2) “ECO-city”, i.e. the further empowering and diffusion of local coalitions which already integrate all non-car modes of transport; 3) “ELECTRI-city”, i.e. a new ‘electricity vehicles + smart grids’ system established by a coalition led by electric operators. Also, according to Marletto (2014), if not destabilized by policy pressure, the “AUTO-city” will prevail, once the “ECO-city” and the “ELECTRI-city” demand, respectively, a multilevel policy for urban and transport planning and a national innovation and industrial policy. In specific cases, such as South Korea, the options are electric and hydrogen fuel cell vehicles, says Shin, Hwang, Choi (2019). Whereas the paradigm shifts in the transportation sector caused by climate change previously put electric vehicles (EVs) at the center, hydrogen fuel cell vehicles (HFCVs) have recently emerged as a new driver for change. From an environmental perspective, EVs might not represent an effective alternative to traditional vehicles because their emissions potential depends on how the electricity is produced. HFCVs also have the potential to cause greenhouse gases emissions, depending on how the hydrogen is produced. According to IEA (2022) “Brazil is a global leader in second generation biofuels and flex-fuel cars provide a large domestic market.”

As volumes and ranges increase, an appropriate battery value chain is important for ensuring that electric vehicles continue to contribute to sustainability goals. How batteries are used, recycled, or disposed of after their electric vehicle application affects their life-cycle impacts (Global EV Outlook, 2020).

In this scenario, this paper focuses on the lithium-ion battery patent race, from 1990 to 2019, by country, sectors and companies, using patent data from Derwent Innovation Platform, a Clarivate Analytics Group product. After this introduction, the LIB patent race background, materials and methods, the lithium-ion battery patent race results, and final remarks.

2 Lib Patent Race Background

Lithium-ion battery global market is not an isolated issue but related to other subjects such as environmental agenda and governments and companies' intentions and actions to transform electro mobility in reality as soon as possible in some parts of the world.

Environmental challenges are not new, once world population and urban concentration increased a lot in the 20th century. In the 1900's the world had close to 2 billion people and just a few cities had more than 1 million people. In 2020's the world had about 8 billion people, a lot of cities with more than 1 million people and many cities with more than 10 million people, especially in the Americas and Asia. Cities with populations bigger than many countries like Tokyo, Delhi, Shanghai, New York, Mexico City, and São Paulo. This spectacular human concentration had a deep environmental impact as increased water demand and noise and decreased air quality. Petrol is the most important source of energy since the electric-metal-mechanic paradigm, whose price increased substantially afterward the oil shocks in 1970's. The Automobile industry reacts to high fuel prices by offering economic cars. Despite a single engine demanding less fuel, total cars increased substantially and it did not compensate for fossil fuel efficiency consumption.

According to Global Carbon Atlas data, global emissions have grown 3,7 times in 60 years, from 9,15 CO2 millions of tons in 1960 to 33,8 in 2020, with ups and downs. Those ups are related to good economic performance and downs to negative economic events global impact on CO2 emission as 1st oil shock (1973-74), 2nd oil shock (1980-82), URSS collapse (1991-92), Asia crises (1997-98), 2008 financial crises reflect in 2009 global economic performance, China slowdown (2015-16), and 2020 pandemic.

Under an aggregated spatial-temporal perspective, global main polluters (France, Germany, Italy, Spain in Europe, and China, India, Russian Federation, United Kingdom, USA out of Europe) were responsible for 71,5% of global CO2 emissions in 1960, it goes down consistently until 1976 and since 1977 kept close to 60%. Main Europeans' share decreased consistently since 1962, from 15% to 4%. And main non-European polluters decreased consistently from 57,6% in 1960 to 50,3% in 1973, then kept around 50% from 1974 to 2002, and since 2003 increase consistently to 58,4% in 2020. USA share particularly consistently decreased, from 32% in 1960 to 14% in 2020, and China consistently increased, from 4% in 1960's to 15% in 2002 and since an astonishing increase to 31,5% in 2020. India's contribution to CO2 global emission also increases substantially but at a fraction of China's speed.

A second source of data, from IAE (2022), gives us another picture about CO2 emissions, the energy matrix perspective. We pick four examples: China and India, top global in population, USA, the biggest GDP, and Brazil, a global example in clean energy.

In China CO2 emission increase constantly in the last 30 years, from 2089 million of ton (mt) in 1990 to 9876 mt 2019; coal is China the main source of energy, about 2/3

of total; and currently (April 2022), one of every four tons of coal used globally is burned to produce electricity in China. In India, as in China, CO2 emission also increased in the last 30 years constantly from 596 mt in 1990 to 2310 mt in 2019. From 1990 to 2019 oil is about 20%-25% of total Indian energy source, coal 35%-40% and biofuel and waste about 30%-40%. China and India's emission scenario could be worse once they are the most populated countries in 2022, 1,40 billion and 1,38 billion habitants, respectively, but are far away from USA US$ 58,000.00 GDP per capita in 2015 (IAE, 2022). It means that, ceteris paribus, non-green energy consumption in those countries can increase substantially.

In the USA there is the U inverted energy matrix CO2 emission curve: it increases from 4803 mt in 1990 to 5702 mt in 2001, then it decreases to 4744 mt in 2019. From 1990 to 2019 oil was about 40% of total American energy source, coal reduced from 20% to 15%, natural gas increased from 10% to 15%. In Brazil, as in the USA, there is also a U inverted CO2 emission curve: it increases from 185 mt in 1990 to 482 mt 2014, then it decreases to 411 mt in 2019. From 1990 to 2019 oil is about 40% of total Brazilian energy source, biofuel and waste is another 40%, hydro about 10%. Since 1990 gas and nuclear have increased constantly, while coal share has decreased. Wind and solar begin in 2014 but are residual. At least, “Brazil’s energy policies measure up well against the world’s most urgent energy challenges. Access to electricity across the country is almost universal and renewables meet almost 45% of primary energy demand, making Brazil’s energy sector one of the least carbon-intensive in the world” (…) “large hydropower plants account for around 80% of domestic electricity generation, making the Brazilian electricity mix one of the cleanest in the world.” (IEA, 2022).

Considering CO2 emissions level and energy matrix, it is not a surprise that governments and companies looked for other options such as zero emission vehicles, electric cars, and electric mobility. It is also not a surprise time-spatial heterogeneity policy.

On the government side, California State (CS) in the USA is a world pioneer in zero emission vehicles target and electric cars public policies. In 1960`s California approved a set of environmental laws under Federal Air Quality Act (1967), that give CS instruments to set up his own vehicle pollution emission level. In 1960 CS created the California Air Resources Board (CARB), now part of California Environmental Protection Agency. CARB is the authority that decides air quality control and no aggressive environmental rules for the automobile industry. Since 1990 there has been the Low-Emission Vehicle (LEV) and the Zero-Emission Vehicle (ZEV) program, the Battery Electric Vehicles program and the New Generation of Vehicles partnership with the national automobilist industry (BEDSWORHT and TAYLOR, 2007). ZEV in particular is an environment benchmark program. It encourages R&D in many electromobility technologies such as electric vehicles, hybrid engines, plug-in, fuel cell, hydrogen and low emission fossil fuel engines (KARLSBERG, 2000).

Many countries plan deep CO2 emission reduction between 2030 and 2050. According to IEA (2021) Norway plan 100% zero emission vehicles up to 2025, Demark, Ireland, Iceland, Israel, Netherland, Scotia, Singapore, Slovenia, Sweden (2030), Cape Verde, United Kingdom (2035), France, Canada, Portugal and Spain (2040), Costa Rica and Germany (2050). The United Kingdom plans 100% electric vehicles up to 2030, China and Japan up to 2035. And others target zero emissions as Sweden (2045), Canada, Chile, Fiji, South Korea, New Zealand, Norway, United Kingdom and all European Union (2050).

Externalities support government intervention (Pigou, 1932; Springel, 2021), EV is an example of positive externality, and it justify many Electric Vehicles (EV) governments tax incentive to the options available as Battery Electric Vehicle (BEV),

Plug-in Hybrid Electric Vehicle (PHEV), Fuel Cell Electric Vehicle (FCEV) and Battery Electric Vehicle (BEV). According to IEA (2020) some countries give tax refunds as Norway (25% VAT back to BEV) and USA (US$ 7.500,00 cash back to BEV and PHEV). Many countries give subsidies, whose range varies from US$ 1.200,00 to US$ 20.800,00, summed up in TABLE 1. It is not a surprise that a tech battery patent race to give EV performance as Internal Combustion Engine (ICE), as we show in the result section.

Table 1. subsides to EV, selected countries, values in US$.

COUNTRY	BEV	PHEV	FCEV
CHINA	3.200,00	1.200,00	
SOUTH KOREA	6.700,00		18.800,00
JAPAN	3.700,00	1.800,00	20.800,00
GERMANY	6.800,00		
SPAIN	6.200,00	6.200,00	
FRANCE	6.800,00	6.800,00	6.800,00
UK	3.800,00	3.800,00	
SWEDEN	6.500,00		6.500,00
CANADA	3.700,00	3.700,00	3.700,00

SOURCE: IEA (2020). LEGEND: Battery Electric Vehicle (BEV), Plug-in Hybrid Electric Vehicle (PHEV), Fuel Cell Electric Vehicle (FCEV).

On the company's side some saw zero emission target as an opportunity to create new market, and put substantially efforts to find solution that fits consumers budget and needs. Information and Communication Technological (ICT) companies were particularly well positioned in battery market and it is not a coincidence they leading firms in this field. Sony was the first in 1991. In fact, cars lithium-ion battery has the same technology used in others ICT devices, as laptops and cell phones. A kind of technological spillover from ICT to automobilist industry. Once battery is a key electric car component, other countries also decided local production. Investments, fusions, acquisitions and R&D partnerships between traditional ICT and automobilist, as well new players, are now part of this business as Chen, Xu (2022) and Wesseling, Faber, Hekkert (2014) points out.

Korean electric motor industry analysis confirms it: this industry features strong innovation activities and scope for knowledge spillovers. These establishments, primarily engage in manufacturing electric motors (except internal combustion engine starting motors), power generators (except battery charging alternators for internal combustion engines), motor generator sets (except turbine generator set units), and transformers, are an intermediate input sector, where low cost and energy e efficiency are the key indicators of a firm's technological position. Nevertheless, it is not a "laissez faire, laissez passer" inertia, but a Korean industry and innovation policy as response to Asian financial crisis in 1997, a strong science and technology initiative to promote knowledge-intensive industries (Chen, Xu, 2022).

An in depth analysis of patent data from 1990 to 2010 from European Patent Office's Global Patent Index by Wesseling, Faber, Hekkert, (2014) identify four global waves of Low Emission Vehicle (LEV) development: i) the broken wave of Battery Electric Vehicle (BEV) development in the early nineties and was initiated by the demonstration of GM's working BEV prototype, ii) the development of Hydrogen Fuel Cell Vehicle (HFCV) from the late 1990s to the mid-2000s, iii) the continued wave of Hybrid Electric Vehicle (HEV) development that led to commercial success and which started in the late nineties, iv) the BEV development that started in approximately 2006.

Wesseling, Faber, Hekkert (2014) also identified the main company in each wave. The first, in the early nineties, GM was BEV main firm. In the second, from the late 1990s to the mid-2000s, Daimler moving first into HFCV development. The third was the continued wave of HEV development that led to commercial success, and which started in the late nineties, and was pioneered by Toyota and Honda, who brought HEVs to market in 1997 and 1998 respectively. And the fourth was different from previously once new entrants reportedly played an important role in triggering it: numerous new entrants began producing BEVs from 2006 onwards, whereas most incumbent car manufacturers did not introduce their own prototype or production vehicles until 2009.

In sum, on one hand CO2 increase emission and no green energy matrix, on the other governments and companies looking for other non-pollution option transport options as zero emission vehicles, electric cars and electric mobility. This option to reduce CO2 emission had incentive research in batteries, lithium-ion particularly. Let's check in details the lithium-ion patent race to electric devices and electric vehicles.

3 Materials And Methods: Lithium-Ion Battery Patent Data

We have got two sets of patent data from the restricted access Derwent Innovation Platform, a Clarivate Analytics Group product: 1) Lithium-ion Battery for Electronic Devices (LIB-ED), as cell phones and laptops; 2) Lithium-ion Battery for Electric Vehicle (LIB-EV). For group 1 (LIB-ED), initially a filter was made by DWPI code (Derwent World Patent Index) combining the subgroups X16-B01F1 and P8 or T or W. Then another search was made by IPC code (International Patent Classification), combining the specific subgroups H01M and H02H or H02J. Finally, the platform is subjected to a combination of the two results obtained, generating a single database. The final extraction was done using the INPADOC (International Patent Documentation) function. For group 2 (LIB-EV), initially a filter was made by DWPI code combining the subgroups X1-B01F1 and X1. Then another search was performed by IPC code, combining the specificity subgroups (B60K and H01M). Finally, the platform is subjected to a combination of the two results obtained, generating a single database. The final operation was done using the INPADOC function.

4 Results and Discussion

The set of TABLES 2, 3 and 4 and GRAPHS 1,2 and 3, are about Electric Devices (ED) battery patent race.

TABLE 2A give us total patents by country in decades 1990's, 2000's and 2010's. TABLE 2B give us country patent share in each decade. In 1990's Japan was the leader, with 64,7%, followed by USA (14%) and Germany (11%), China (4%) and South Korea (2,7%). In 2000's Japan kept as leader (55%), China (20,5%) jump to the second, USA (13%) was the third. And in 2010's China (45%) become the first, Japan (29%) the second and USA (14%) kept the third. TABLE 2C give us country patent effort in each decade, and 2010's is the main decade to top 5: China (86,4%), South Korea (79,4%), USA (70%), Japan (53,6%) and South Korea (45,8%). GRAPH 1 show us main countries electric devices battery patent share year by year, from 1990-2019. It is clears Japan falls from 64% in 1990 to 18,7% in 2019, and China astonish rise, from 1% in 1990 to 15% in 2004, 40% in 2013, and 59% in 2019.

TABLE 3A give us total patents by sector in that three decades. TABLE 3B give us sector patent share in each decade. ICT is the leader with 83,8% in 1990's, 77,4% in 2000's, and 68,3% in 2010's, i.e. a slightly decrease through decades. Automotive is the second, far behind ICT, with 10,3% in 1990's, 16,9% in 2000's, and 22,6% in 2010's, i.e. a slightly increase through decades. ICT and auto together are responsible for 9/10

sectorial patents in those decades. TABLE 3C give us sectorial patent effort in each decade, and 2010's is the main decade for all sectors, ICT (59%) and automotive (72%) particularly. GRAPH 2 show us main sectors electric devices battery patent share year by year, from 1990-2019. It is clear ICT slightly decrease from 80,4% in 1960 to 63,3% 2014, and a small recover from 2015, back to 70,4% in 2019, and automotive slightly increase from 14% to 20%, as well other residual sectors.

At least, TABLE 4A give us total patents by companies in that three decades. TABLE 4B give us company patent share in each decade. In this set of 20 companies, we have three groups: one that decrease participation (Panasonic, Sony, NEC, Toshiba, Hitachi, GS Yuasa, Canon, Nissan and Fujitsu), other that increase (Toyota, Samsung, LG, Denso, Bosh, Sumitomo, BBK and Murata) and a third that swing between ups and downs (Showa Denko, Foxconn and Minebeamitsumi). We highlight Panasonic (from 30,5% in 1990's to 15,15% in 2010's) and Sony (from 14% in 1990's to 3% in 2010's) decrease and Toyota (from 3,3% in 1990's to 14,3% in 2010's) and LG (from 0% in 1990's to 8,2% in 2010's) increase. TABLE 4C give us company patent effort in each decade. Here we have four groups: one whose effort is concentrated in 2000's (Sony), a second whose effort is slightly concentrated in 2010's (Panasonic, NEC, Canon, Nissan, Fujitsu, GS Yuasa, Foxconn, Showa Denko), a third substantially in 2010's (Samsung, Toshiba, Hitachi), and a fourth deep concentrated in 2010's (Toyota, LG, BBK and Murata). GRAPH 3A shows us year by year companies ups and downs, and GRAPH 3B focus on Panasonic (40% in 1993, 7% in 2017), Sony (20% in 1997, 1% in 2019), Toyota (1% in 1990, 16,4% in 2016), and LG (0% between 1990 and 2000, 14% in 2019).

In sum, Countries change position, and China became leader, Japan, USA South Korea and Germany falls behind, sectors kept position, ICT and automotive share more than 90%, and companies change position, with Panasonic and Sony lost substantial position, and Toyota and LG got important patent share. The graphs give us a picture of ED battery technological apropriability evolution in the last three decades under three perspectives: country, sector and companies. We will back to it in the discussion section.

Tables 2 A, B, C. Lithium-Ion Electric Devices Battery Patent Data, Main Countries

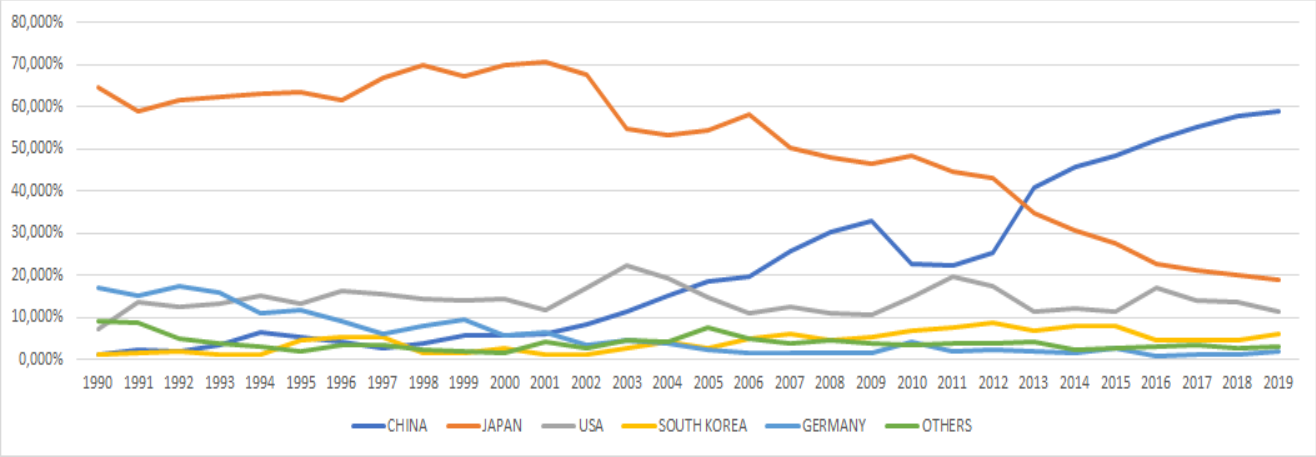
TABLE 2A	1990'S	2000'S	2010'S	TOTAL
CHINA	190	2.734	18.582	21.506
JAPAN	3.070	7.347	12.034	22.451
USA	665	1.778	5.761	8.204
SOUTH KOREA	129	529	2.600	3.258
GERMANY	514	370	748	1.632
OTHERS	172	545	1.310	2.027
TOTAL	4.740	13.303	41.035	59.078

TABLE 2B	1990'S	2000'S	2010'S
CHINA	4,008%	20,552%	45,283%
JAPAN	64,768%	55,228%	29,326%
USA	14,030%	13,365%	14,039%
SOUTH KOREA	2,722%	3,977%	6,336%
GERMANY	10,844%	2,781%	1,823%
OTHERS	3,629%	4,097%	3,192%
TOTAL	100,000%	100,000%	100,000%

TABLE 2C	1990'S	2000'S	2010'S	TOTAL
CHINA	0,883%	12,713%	86,404%	100,000%
JAPAN	13,674%	32,725%	53,601%	100,000%
USA	8,106%	21,672%	70,222%	100,000%
SOUTH KOREA	3,959%	16,237%	79,804%	100,000%
GERMANY	31,495%	22,672%	45,833%	100,000%
OTHERS	8,485%	26,887%	64,628%	100,000%

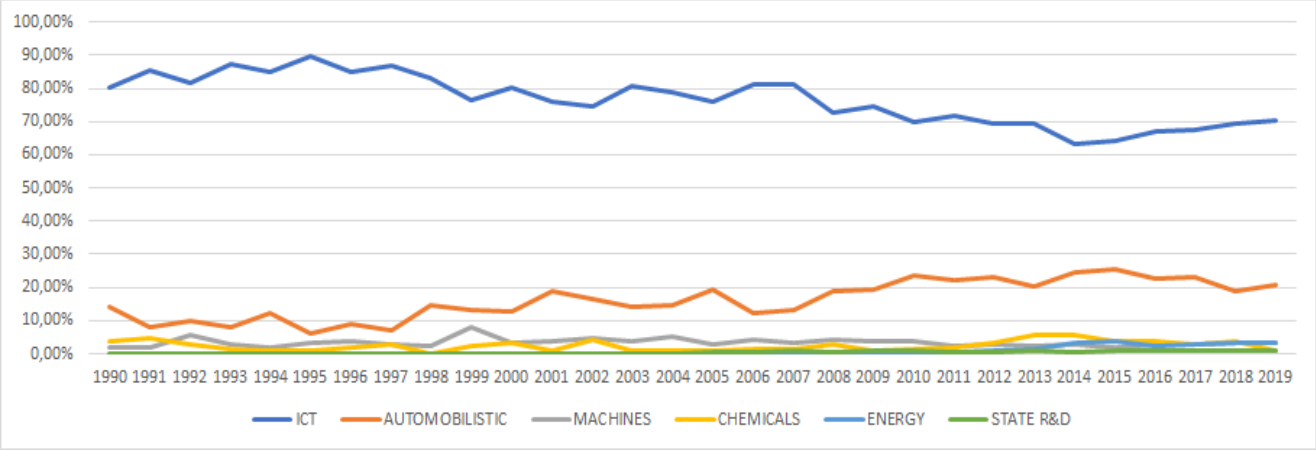
Source: Author’s elaboration from Derwent Innovation Platform.

Graph 1. Electric Devices Battery Patent Share, 1990-2019, Main Countries



Source: Author's elaboration from Derwent Innovation Platform.

Graph 2. Lithium-Ion Electric Devices Battery Patent Share, 1990-2019, Main Sectors



Source: Author's elaboration from Derwent Innovation Platform.

Tables 3 A, B, C. Lithium-Ion Electric Devices Battery Patent Share, Main Sectors

TABLE 3A	1990'S	2000'S	2010'S	TOTAL
ICT	1950	4853	9826	16629
AUTOMOBILISTIC	241	1015	3250	4506
MACHINES	91	246	417	754
CHEMICALS	45	114	470	629
ENERGY	0	10	306	316
STATE R&D	0	32	115	147
TOTAL	2327	6270	14384	22981

TABLE 3B	1990'S	2000'S	2010'S
ICT	83,80%	77,40%	68,31%
AUTOMOBILISTIC	10,36%	16,19%	22,59%
MACHINES	3,91%	3,92%	2,90%
CHEMICALS	1,93%	1,82%	3,27%
ENERGY	0,00%	0,16%	2,13%
STATE R&D	0,00%	0,51%	0,80%
TOTAL	100,00%	100,00%	100,00%

TABLE 3C	1990'S	2000'S	2010'S	TOTAL
ICT	11,73%	29,18%	59,09%	100,00%
AUTOMOBILISTIC	5,35%	22,53%	72,13%	100,00%
MACHINES	12,07%	32,63%	55,31%	100,00%
CHEMICALS	7,15%	18,12%	74,72%	100,00%
ENERGY	0,00%	3,16%	96,84%	100,00%
STATE R&D	0,00%	21,77%	78,23%	100,00%
TOTAL	10,13%	27,28%	62,59%	100,00%

Source: Author's elaboration from Derwent Innovation Platform.

Tables 4 A, B, C. Lithium-Ion Electric Devices Battery Patent Share, Main Companies

TABLE 4A	**1990'S**	**2000'S**	**2010'S**	**TOTAL**
PANASONIC CORPORATION	575	1.445	1.625	3.645
TOYOTA MOTOR CORP	63	306	1.536	1.905
SAMSUNG SDI CO LTD	51	342	839	1.232
SONY CORP	263	547	326	1.136
LG CHEM LTD.	-	172	882	1.054
NEC CORP	152	331	567	1.050
TOSHIBA CORP	146	231	597	974
HITACHI LTD	98	171	514	783
DENSO CORP	34	157	450	641
BOSCH (ROBERT) GMBH	38	123	473	634
GS YUASA CORPORATION	86	163	334	583
SUMITOMO ELECTRIC INDUSTRIES	16	121	445	582
SHOWA DENKO K.K.	42	101	329	472
FOXCONN	21	177	266	464
CANON INC	90	141	216	447
BBK ELECTRONICS	-	-	442	442
NISSAN MOTOR CO. LTD.	62	171	194	427
FUJITSU LIMITED	112	116	174	402
MURATA MANUFACTURING CO. LTD.	6	42	309	357
MINEBEAMITSUMI INC	29	117	205	351
TOTAL	**1.884**	**4.974**	**10.723**	**17.581**

Source: Author's elaboration from Derwent Innovation Platform.

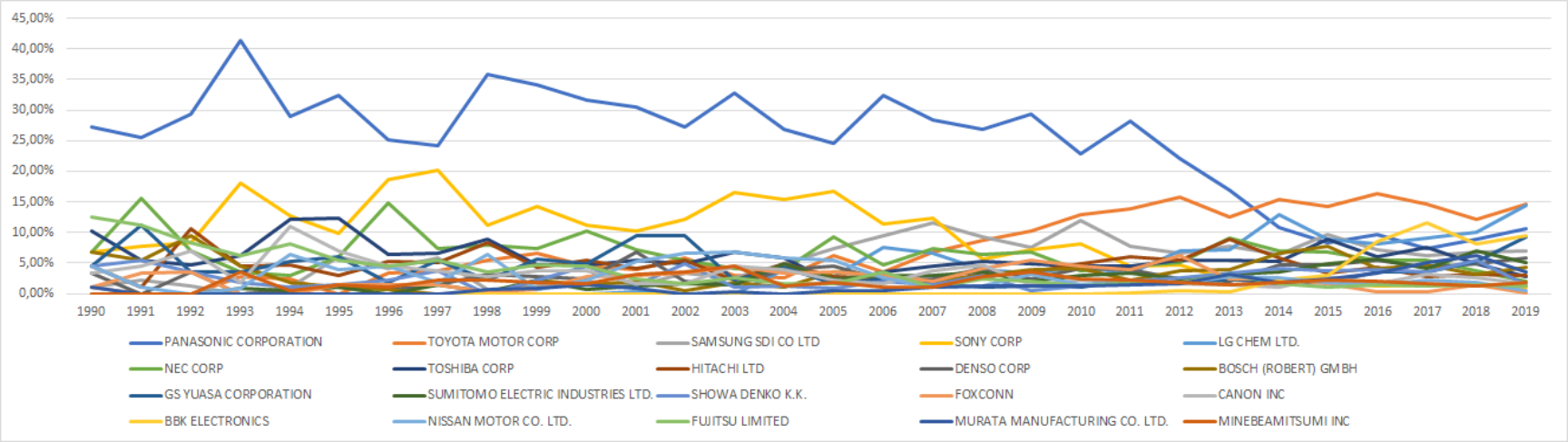
TABLE 4B	1990'S	2000'S	2010'S	TOTAL
PANASONIC CORPORATION	30,52%	29,05%	15,15%	20,73%
TOYOTA MOTOR CORP	3,34%	6,15%	14,32%	10,84%
SAMSUNG SDI CO LTD	2,71%	6,88%	7,82%	7,01%
SONY CORP	13,96%	11,00%	3,04%	6,46%
LG CHEM LTD.	0,00%	3,46%	8,23%	6,00%
NEC CORP	8,07%	6,65%	5,29%	5,97%
TOSHIBA CORP	7,75%	4,64%	5,57%	5,54%
HITACHI LTD	5,20%	3,44%	4,79%	4,45%
DENSO CORP	1,80%	3,16%	4,20%	3,65%
BOSCH (ROBERT) GMBH	2,02%	2,47%	4,41%	3,61%
GS YUASA CORPORATION	4,56%	3,28%	3,11%	3,32%
SUMITOMO ELECTRIC INDUSTRIES	0,85%	2,43%	4,15%	3,31%
SHOWA DENKO K.K.	2,23%	2,03%	3,07%	2,68%
FOXCONN	1,11%	3,56%	2,48%	2,64%
CANON INC	4,78%	2,83%	2,01%	2,54%
BBK ELECTRONICS	0,00%	0,00%	4,12%	2,51%
NISSAN MOTOR CO. LTD.	3,29%	3,44%	1,81%	2,43%
FUJITSU LIMITED	5,94%	2,33%	1,62%	2,29%
MURATA MANUFACTURING CO. LTD.	0,32%	0,84%	2,88%	2,03%
MINEBEAMITSUMI INC	1,54%	2,35%	1,91%	2,00%
TOTAL	100,00%	100,00%	100,00%	100,00%

Source: Author’s elaboration from Derwent Innovation Platform.

TABLE 4C	1990'S	2000'S	2010'S	TOTAL	2010/ TOTAL
PANASONIC CORPORATION	15,78%	39,64%	44,58%	100,00%	44,58%
TOYOTA MOTOR CORP	3,31%	16,06%	80,63%	100,00%	80,63%
SAMSUNG SDI CO LTD	4,14%	27,76%	68,10%	100,00%	68,10%
SONY CORP	23,15%	48,15%	28,70%	100,00%	28,70%
LG CHEM LTD.	0,00%	16,32%	83,68%	100,00%	83,68%
NEC CORP	14,48%	31,52%	54,00%	100,00%	54,00%
TOSHIBA CORP	14,99%	23,72%	61,29%	100,00%	61,29%
HITACHI LTD	12,52%	21,84%	65,64%	100,00%	65,64%
DENSO CORP	5,30%	24,49%	70,20%	100,00%	70,20%
BOSCH (ROBERT) GMBH	5,99%	19,40%	74,61%	100,00%	74,61%
GS YUASA CORPORATION	14,75%	27,96%	57,29%	100,00%	57,29%
SUMITOMO ELECTRIC INDUSTRIES	2,75%	20,79%	76,46%	100,00%	76,46%
SHOWA DENKO K.K.	8,90%	21,40%	69,70%	100,00%	69,70%
FOXCONN	4,53%	38,15%	57,33%	100,00%	57,33%
CANON INC	20,13%	31,54%	48,32%	100,00%	48,32%
BBK ELECTRONICS	0,00%	0,00%	100,00%	100,00%	100,00%
NISSAN MOTOR CO. LTD.	14,52%	40,05%	45,43%	100,00%	45,43%
FUJITSU LIMITED	27,86%	28,86%	43,28%	100,00%	43,28%
MURATA MANUFACTURING CO. LTD.	1,68%	11,76%	86,55%	100,00%	86,55%
MINEBEAMITSUMI INC	8,26%	33,33%	58,40%	100,00%	58,40%
TOTAL	10,72%	28,29%	60,99%	100,00%	60,99%

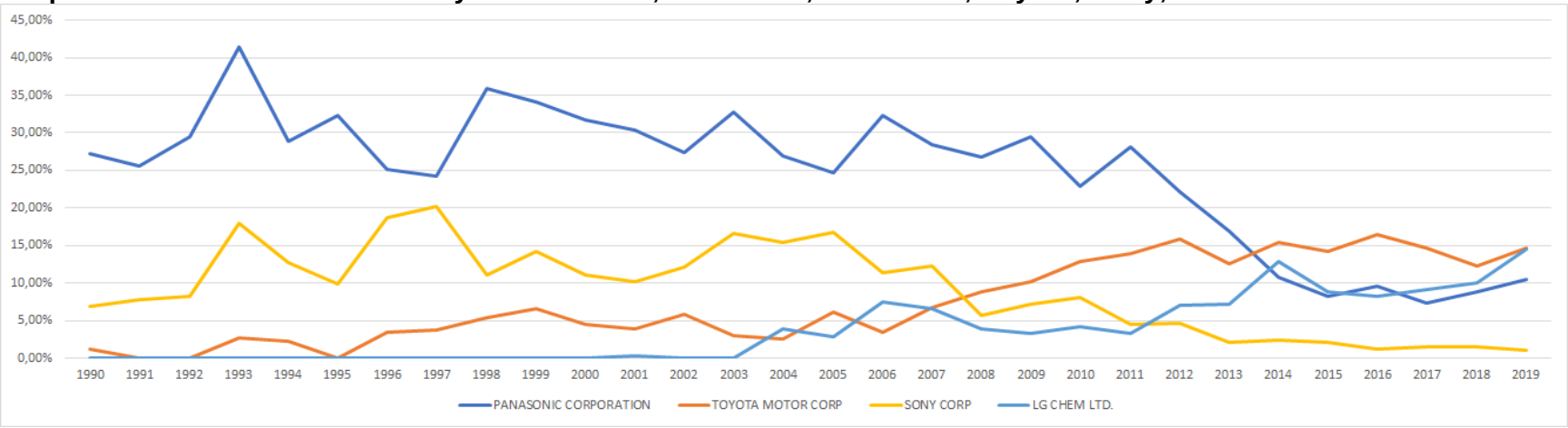
Source: Author's elaboration from Derwent Innovation Platform.

Graph 3A. Lithium-Ion Electric Devices Battery Patent Share, 1990-2019, Main Companies



Source: Author's elaboration from Derwent Innovation Platform.

Graph 3B. Electric Devices Battery Patent Share, 1990-2019, Panasonic, Toyota, Sony, LG



Source: Author's elaboration from Derwent Innovation Platform.

The set of TABLES 5,6 and 7 and GRAPHS 4,5 and 6, are about Electric Vehicles (EV) battery patent race.

TABLE 5A give us total patents by country in decades 1990's, 2000's and 2010's. TABLE 5B give us country patent share in each decade. In 1990's Japan was the leader, with 70,7%, Germany (11,6%), USA (8%) far away, China (1,3%) and South Korea (1,3%) out of the mirror. In 2000's Japan kept as leader (67%), USA (8%) kept the second, China (7,5%) jump to the third, Germany down to 5,8% and South Korea up to 4%. In 2010's Japan (36%) kept as leader, but half 1990's share, China (27,5%) jump to the second, USA kept the third (14%), and South Korea (10,5%) cross Germany (5,3%). TABLE 5C give us country patent effort in each decade, and 2010's is the main decade to all main countries: China (95%), Japan (71%), USA (88,8%), South Korea (93%), Germany (78,7%). GRAPH 4 show us main countries electric vehicles battery patent share year by year, from 1990-2019. We highlight Japan falls from 70% between 1990 and 2009, to 22,7% in 2019, and China astonish rise, below 10% until 2005, between 11% and 18% from 2006 to 2014, and 2017 (39%) cross Japan (30%) in EV battery patent share.

TABLE 6A give us total patents by sector in that three decades. TABLE 6B give us sector patent share in each decade. Automotive is the leader with 73% in 1990's, 74% in 2000's, and 59% in 2010's, a substantial down. ICT is the second with 23% in 1990's, 22% in 2000's, and 36% in 2010's, a substantial up. Auto and ICT together are responsible for 95/100 sectorial patents in all decades. TABLE 6C give us sectorial patent effort in each decade, and 2010's is the main decade for all sectors, auto (76%) and ICT (87%) particularly. GRAPH 5 show us main sectors electric devices battery patent share year by year, from 1990-2019. Auto share is between 60% and 80%, and ICT between 20% and 40%, with a few exceptions.

At least, TABLE 7A give us total patents by companies in that three decades. TABLE 7B give us company patent share in each decade. In this set of 20 companies Toyota is the leader with 30,5% of total patents, followed by LG with 12,32%, then a second group around 8% (Honda and Panasonic) and a third group between 4% and 6% (Samsung, Hyundai and Bosh). Those companies share together is 74%. We call attention to Honda (from 24% to 6%) and Panasonic (11% to 7%) decrease, and Bosh (from 0% to 7%) and Samsung (from 0,6% to 5%) increase. TABLE 7C give us company patent effort in each decade. All companies concentrated in 2010's, but Toyota, Honda, Hyundai, Denso, GM and Showa Denko made a significant effort in 2000's.

GRAPH 6A shows us year by year companies ups and downs. Honda begin as leader, but lost position to Toyota that kept as first since 1995, except in 1997 and 2002 for a small margin. GRAPH 6B shows clear that Honda lost position to Toyota in 1996, then to Panasonic in 2006, then to LG in 2011. In 2019 Honda get Panasonic position.

In sum, about countries, Japan falls from 70% between 1990 and 2009, to 22,7% in 2019, and China astonish rise, below 10% until 2005, between 11% and 18% from 2006 to 2014, and 2017 (39%) cross Japan (30%) in EV battery patent share. About sectors, auto and ICT together are responsible for 95/100 sectorial patents in all decades. The 2010's is the main decade for all countries and sectors. And about companies, we call attention to Honda (from 24% to 6%) and Panasonic (11% to 7%) decrease, and Bosh (from 0% to 7%) and Samsung (from 0,6% to 5%) increase. The graphs give us a picture of EV battery technological apropriability evolution in the last three decades under three perspectives: country, sector and companies. We will also back to it in the discussion section.

Tables 5 A, B, C. Lithium-Ion Eletric Vehicles Battery Patent Data, Main Countries, 1990's, 2000's, 2010's

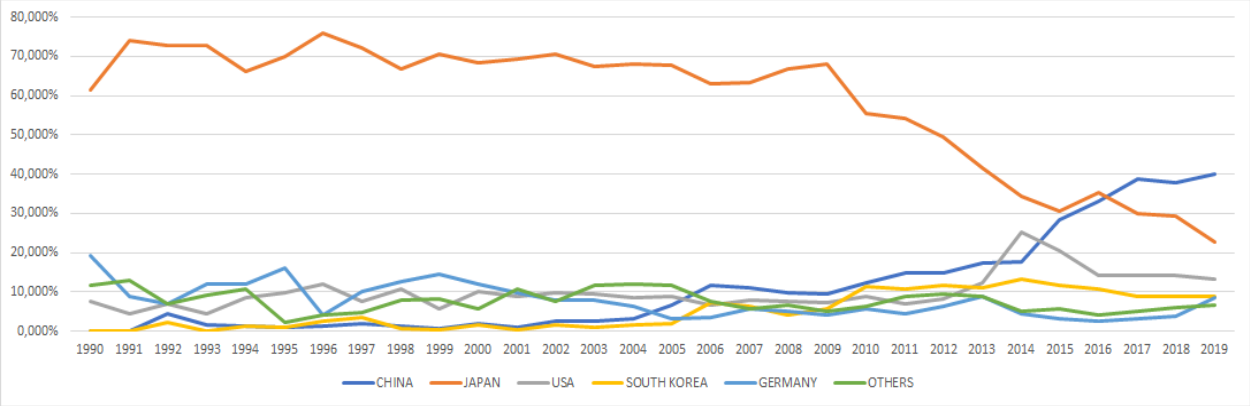
TABLE 5A	1990'S	2000'S	2010'S	TOTAL
CHINA	14	548	10.571	11.133
JAPAN	771	4.883	13.870	19.524
USA	89	587	5.348	6.024
SOUTH KOREA	14	289	4.045	4.348
GERMANY	127	421	2.029	2.577
OTHERS	76	548	2.527	3.151
TOTAL	1.091	7.276	38.390	46.757

TABLE 5B	1990'S	2000'S	2010'S
CHINA	1,283%	7,532%	27,536%
JAPAN	70,669%	67,111%	36,129%
USA	8,158%	8,068%	13,931%
SOUTH KOREA	1,283%	3,972%	10,537%
GERMANY	11,641%	5,786%	5,285%
OTHERS	6,966%	7,532%	6,582%
TOTAL	100%	100%	100%

TABLE 5C	1990'S	2000'S	2010'S	TOTAL
CHINA	0,126%	4,922%	94,952%	100,000%
JAPAN	3,949%	25,010%	71,041%	100,000%
USA	1,477%	9,744%	88,778%	100,000%
SOUTH KOREA	0,322%	6,647%	93,031%	100,000%
GERMANY	4,928%	16,337%	78,735%	100,000%
OTHERS	2,412%	17,391%	80,197%	100,000%

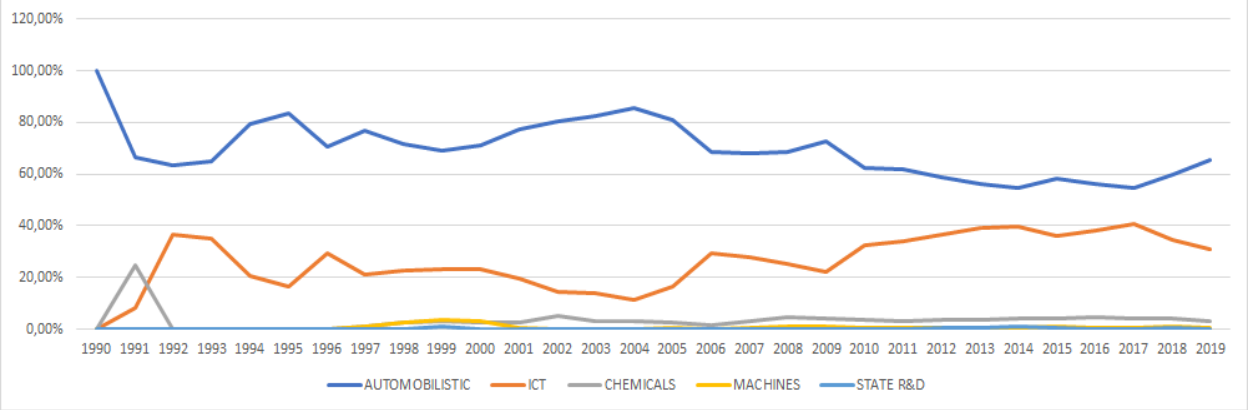
Source: Author's elaboration from Derwent Innovation Platform.

Graph 4. Lithium-Ion Eletric Vehicles Battery Patent Data, Main Countries, 1990-2019



Source: Author's elaboration from Derwent Innovation Platform.

Graph 5. Lithium-Ion Eletric Vehicles Battery Patent Data, Main Sectors, 1990-2019



Source: Author's elaboration from Derwent Innovation Platform.

Tables 6 A, B, C. Lithium-Ion Eletric Vehicles Battery Patent Data, Main Sectors, 1990's, 2000's, 2010's

TABLE 6A	1990'S	2000'S	2010'S	TOTAL
AUTOMOBILISTIC	500	4.134	14.526	19.160
ICT	161	1.219	8.977	10.357
CHEMICALS	13	197	942	1.152
MACHINES	11	48	152	211
STATE R&D	2	2	97	101
TOTAL	687	5.600	24.694	30.981

TABLE 6B	1990'S	2000'S	2010'S
AUTOMOBILISTIC	72,78%	73,82%	58,82%
ICT	23,44%	21,77%	36,35%
CHEMICALS	1,89%	3,52%	3,81%
MACHINES	1,60%	0,86%	0,62%
STATE R&D	0,29%	0,04%	0,39%
TOTAL	100,00%	100,00%	100,00%

TABLE 6C	1990'S	2000'S	2010'S	TOTAL
AUTOMOBILISTIC	2,61%	21,58%	75,81%	100,00%
ICT	1,55%	11,77%	86,68%	100,00%
CHEMICALS	1,13%	17,10%	81,77%	100,00%
MACHINES	5,21%	22,75%	72,04%	100,00%
STATE R&D	1,98%	1,98%	96,04%	100,00%

Source: Author's elaboration from Derwent Innovation Platform.

Tables 7 A, B, C. Lithium-Ion Eletric Vehicles Battery Patent Data, Main Companies, 1990's, 2000's, 2010's

TABLE 7A	1990'S	2000'S	2010'S	TOTAL
TOYOTA MOTOR CORP	117	1571	4.857	6545
LG CHEM LTD.	0	126	2.517	2643
PORSCHE AUTOMOBIL HOLDING SE	5	21	694	720
HONDA MOTOR CO. LTD.	84	532	1.026	1642
BOSCH (ROBERT) GMBH	0	66	1.215	1281
PANASONIC CORPORATION	39	468	1.173	1680
HYUNDAI MOTOR CO.	3	124	972	1099
BAYERISCHE MOTOREN WERKE AG (BMW)	4	15	323	342
FORD MOTOR CO.	1	37	559	597
SAMSUNG SDI CO LTD	2	39	934	975
DENSO CORP	19	124	507	650
SUMITOMO ELECTRIC INDUSTRIES LTD.	17	66	520	603
CONTEMPORARY AMPEREX TECHNOLOGY LTD	0	1	155	156
GENERAL MOTORS CORP	14	101	419	534
GS YUASA CORPORATION	30	65	528	623
BYD CO LTD	0	19	277	296
SHOWA DENKO K.K.	10	108	378	496
KWANG YANG MOTOR CO. LTD.	0	2	55	57
SEMICONDUCTOR ENERGY LABORATORY CO. LTD.	0	1	176	177
MURATA MANUFACTURING CO. LTD.	0	6	337	343
TOTAL	345	3492	17622	21459

Source: Author's elaboration from Derwent Innovation Platform.

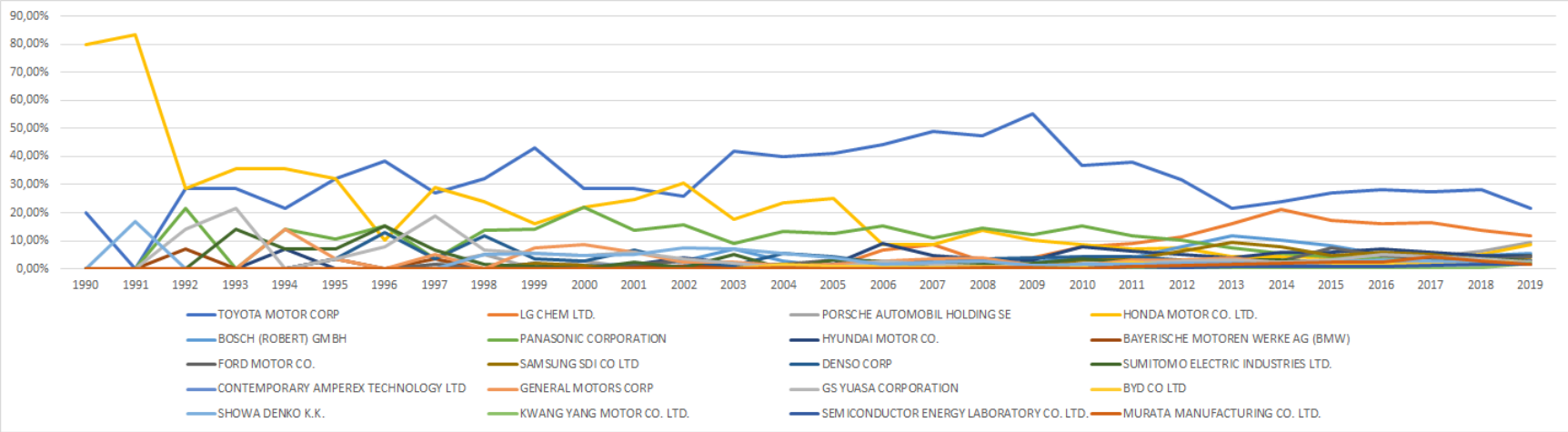
TABLE 7B	1990'S	2000'S	2010'S	TOTAL
TOYOTA MOTOR CORP	33,91%	44,99%	27,56%	30,50%
LG CHEM LTD.	0,00%	3,61%	14,28%	12,32%
PORSCHE AUTOMOBIL HOLDING SE	1,45%	0,60%	3,94%	3,36%
HONDA MOTOR CO. LTD.	24,35%	15,23%	5,82%	7,65%
BOSCH (ROBERT) GMBH	0,00%	1,89%	6,89%	5,97%
PANASONIC CORPORATION	11,30%	13,40%	6,66%	7,83%
HYUNDAI MOTOR CO.	0,87%	3,55%	5,52%	5,12%
BAYERISCHE MOTOREN WERKE AG (BMW)	1,16%	0,43%	1,83%	1,59%
FORD MOTOR CO.	0,29%	1,06%	3,17%	2,78%
SAMSUNG SDI CO LTD	0,58%	1,12%	5,30%	4,54%
DENSO CORP	5,51%	3,55%	2,88%	3,03%
SUMITOMO ELECTRIC INDUSTRIES LTD.	4,93%	1,89%	2,95%	2,81%
CONTEMPORARY AMPEREX TECHNOLOGY LTD	0,00%	0,03%	0,88%	0,73%
GENERAL MOTORS CORP	4,06%	2,89%	2,38%	2,49%
GS YUASA CORPORATION	8,70%	1,86%	3,00%	2,90%
BYD CO LTD	0,00%	0,54%	1,57%	1,38%
SHOWA DENKO K.K.	2,90%	3,09%	2,15%	2,31%
KWANG YANG MOTOR CO. LTD.	0,00%	0,06%	0,31%	0,27%
SEMICONDUCTOR ENERGY LABORATORY LTD.	0,00%	0,03%	1,00%	0,82%
MURATA MANUFACTURING CO. LTD.	0,00%	0,17%	1,91%	1,60%
TOTAL	100,00%	100,00%	100,00%	100,00%

Source: Author’s elaboration from Derwent Innovation Platform.

TABLE 7C	1990'S	2000'S	2010'S	TOTAL	2010/ TOTAL
TOYOTA MOTOR CORP	1,79%	24,00%	74,21%	100,00%	74,21%
LG CHEM LTD.	0,00%	4,77%	95,23%	100,00%	95,23%
PORSCHE AUTOMOBIL HOLDING SE	0,69%	2,92%	96,39%	100,00%	96,39%
HONDA MOTOR CO. LTD.	5,12%	32,40%	62,48%	100,00%	62,48%
BOSCH (ROBERT) GMBH	0,00%	5,15%	94,85%	100,00%	94,85%
PANASONIC CORPORATION	2,32%	27,86%	69,82%	100,00%	69,82%
HYUNDAI MOTOR CO.	0,27%	11,28%	88,44%	100,00%	88,44%
BAYERISCHE MOTOREN WERKE AG (BMW)	1,17%	4,39%	94,44%	100,00%	94,44%
FORD MOTOR CO.	0,17%	6,20%	93,63%	100,00%	93,63%
SAMSUNG SDI CO LTD	0,21%	4,00%	95,79%	100,00%	95,79%
DENSO CORP	2,92%	19,08%	78,00%	100,00%	78,00%
SUMITOMO ELECTRIC INDUSTRIES LTD.	2,82%	10,95%	86,24%	100,00%	86,24%
CONTEMPORARY AMPEREX TECHNOLOGY LTD	0,00%	0,64%	99,36%	100,00%	99,36%
GENERAL MOTORS CORP	2,62%	18,91%	78,46%	100,00%	78,46%
GS YUASA CORPORATION	4,82%	10,43%	84,75%	100,00%	84,75%
BYD CO LTD	0,00%	6,42%	93,58%	100,00%	93,58%
SHOWA DENKO K.K.	2,02%	21,77%	76,21%	100,00%	76,21%
KWANG YANG MOTOR CO. LTD.	0,00%	3,51%	96,49%	100,00%	96,49%
SEMICONDUCTOR ENERGY LABORATORY	0,00%	0,56%	99,44%	100,00%	99,44%
MURATA MANUFACTURING CO. LTD.	0,00%	1,75%	98,25%	100,00%	98,25%

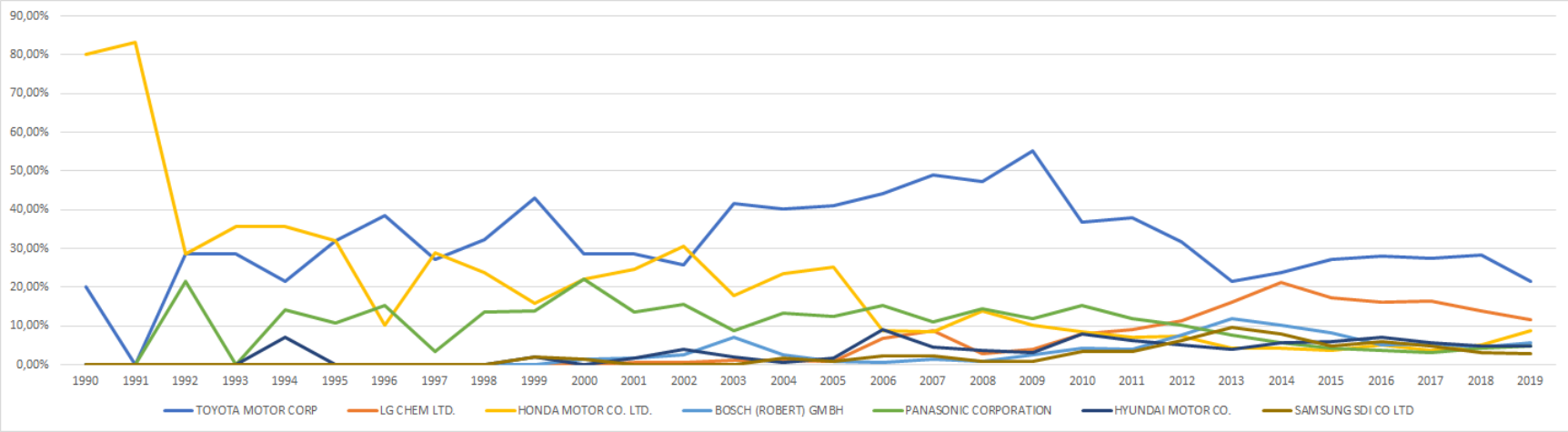
Source: Author's elaboration from Derwent Innovation Platform.

Graph 6A. Electric Vehicles Battery Patent Share, Companies, 1990-2019



Source: Author's elaboration from Derwent Innovation Platform.

Graph 6B. Electric Vehicles Battery Patent Share, Main Companies, 1990-2019



Source: Author's elaboration from Derwent Innovation Platform.

5 Conclusion

CO2 emissions level, energy matrix, zero emission target and electric mobility are connected subjects in a broad debate. The main factor to electric mobility is lithium-ion battery. We got patent data from Derwent Innovation Platform, a Clarivate Analytics Group product from 1990 to 2019, by country, sectors, and companies and conclude that i) China and Japan concentrate the main companies, ii) Information and Communication Technology is the main sector in Electric Devices (ED) battery and Automobilistic in Electric Vehices (EV) battery, iii) some companies in EB and EV, suggesting direct spillovers from ED to EV battery. Others firms are only in ED, others only in EV, iv) Latin American, Africa and Central Asia out of this patent race, v) Brazil has his own green path with biofuels, flex-fuel engines, and clean energy matrix.

From our data it is not clear if patent concentration is a barrier to ED and EV market, as well a barrier to EV as a green option. But is clear China technology protectionism throw his patent system, according to Rassenfosse, Raiteri (2022), that found “robust evidence of antiforeign bias in the issuance of patents in “strategic” technology areas. Foreigners are about fifty per cent more likely to be refused a strategic patent than locals.”. Those “strategic” tech areas biotechnology, information technology, advanced materials technology, advanced manufacturing technology, advanced energy technology, marine technology, laser technology and aerospace technologies.

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