The future of electric batteries in the European automotive industry

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ABSTRACT This paper aims to address the emerging and urgent need for a comprehensive market analysis, forecasting, and data collection of the Gigafactory projects taking place in Europe during this decade. To face the current market monopoly achieved by China, the European Union is now trying to carry out numerous giga-projects throughout the continent. However, it is still not certain which battery cathode chemistry (main differentiating characteristic of the electric batteries on board of EVs), will be the most competitive and appropriate. To face this question, it is important to consider the whole value and supply chain of the electric vehicles and their batteries. Therefore, this thesis aims to provide a data storage tool which could be a a starting point for any further analysis, models, or forecasts to be develop. In addition, not only the database will be created, but it will also be filled, and used to do some analysis with the information contained, such as sensitivity and financial analysis. To sum up, the main goal of the thesis is to create a database developed with MySQL, thought to provide an example of the sort of information which could be gathered by anyone wanting to develop analysis of this specific market (European battery gigafactories). It would be the starting point for different models and algorithms to be developed.

INDEX TERMS Electric vehicles, Lithium-Ion batteries, LFP, NMC, databases, decarbonization, Gigafactory, Europe.

I. INTRODUCTION

Today's society is being forced to change its consumption and life habits due to the negative impact it has been causing on the environment in recent centuries, and especially in recent decades. For this reason, different industrial sectors, such as the transport sector, are having to reduce their emissions throughout their whole product supply chain. Therefore, electric vehicles have been appearing in recent years as the main alternative to combustion vehicles, managing to reach similar ranges and to reduce the high prices that were on the market in recent years.

Of the various components that an electric vehicle has, the most differentiating from an internal combustion vehicle (besides the engine), is the electric battery. As this is the storage system in charge of an EV ("Electric Vehicle"), its capacity requirement is much higher than that of an internal combustion vehicle (ICE from now on), with the consequences on the price, supply, and weight suffered by the vehicle. Still, the automotive industry has tried to lower prices and continues to search for the best possible alternative. There are still doubts about which alternative will have more presence in Europe, and, above all, how they will evolve. The main alternatives, LFP and NMC, with their advantages and disadvantages, continue as the main candidates on the market, although new variants are beginning to exist that affect both the cathode and the anode and the electrolyte of the battery. However, there is a lack of unity and cohesion in the existing data about this market for electric batteries for electric vehicles.
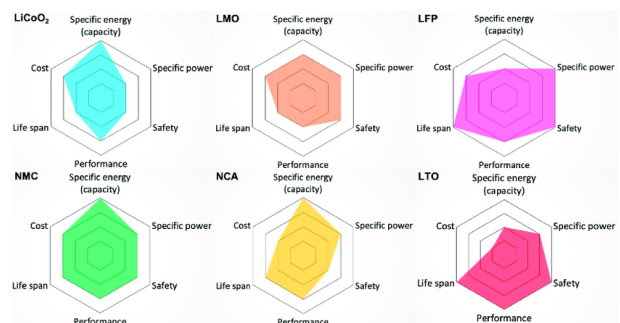

Figure 1. Different types of Lithium-Ion batteries and their characteristics

II. PROJECT DEFINITION

In relation to the lack of unification explained in the abstract regarding battery manufacturers´ data, the present project tries to create a database to be able to store the data of all the companies, factories, and technologies that are to be developed or are being developed in Europe. This would be the starting point from which it would be possible to work with the data in a more unified way, while it does not exist today in the State of the Art.

In addition to this, it is also intended to provide some examples of analysis that could be done with the database created, or with some of the data within it. This database will be created in MySQL following its programming language. The steps followed to develop this part are explained in the section a), corresponding to some examples of analysis, while the section b) corresponds to the database creation.

Therefore, first, the project will have a section in which certain data is analyzed. There will be two main analyses in the thesis:

a) Research and Analysis

i) **Sensitivity analysis** of the battery market regarding the different technologies. For this aim, an exhaustive register of all the Gigafactories which are or will be developed through Europe will be performed. The data registered will be the name of the company, the location, the cathode technology, and capacity to develop, and the initial investment of the project in the case it has not been done yet.

ii) **Financial analysis** of a specific Gigafactory. This analysis is performed to show the order magnitude regarding financial parameters that an investment of this kind would incur. Specifically, the NPV, IRR and Payback Period are calculated for the specific project of the battery manufacturing plant to be built in Sagunto (Valencia) by the automotive group Volkswagen,

Second, the Database is created.

b) Database

As it can be seen and will be explained more in detail in the following section, this part counts with 4 main steps. The first one is the creation of the logical scheme, in which the primary and foreign keys are added, as well as the different relations. This is the scheme from which the database is be created. The second step corresponds to the creation of the Database itself in MySQL, using the MySQL programming language. Then, the Database is filled with some of the data collected in the section "Research and analysis", while in the last part, "Queries", some of this data is checked and showed in the screen. A scheme of the whole process is shown below
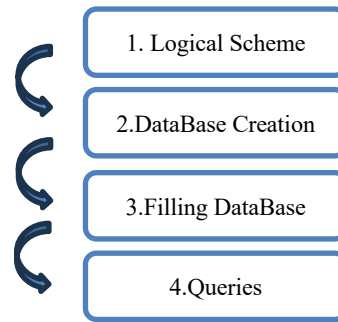

Figure 2: Sequence of the Database implementation

III. RESEARCH AND ANALYSIS

i) SENSITIVITY ANALYSIS

To develop both parts, but specifically the one regarding the Sensitivity analysis, a collection of data is needed. For this aim, deep research has been performed to get as much information as possible about the European Gigafactories. The data collected is listed below.

- Name of the company
- Location of the plant (city and country)
- Battery Cathode Chemistry to be produced.
- Initial investment of the project
- Capacity produced (for each single year 2023 to 2030)

The result obtained is a table with 31 rows (regarding the number of Gigafactories present in Europe in this decade), with a percentage of uncertainty regarding the cathode technology to be developed, as it is impossible to know what certain companies will be producing. Therefore, the final graph obtained is shown below.
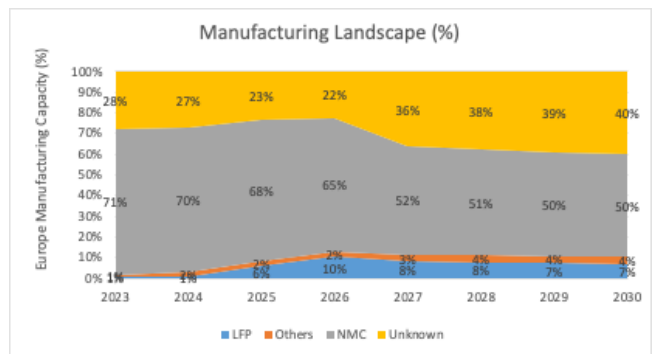

Figure 3: Manufacturing landscape for the rest of the decade

As it can be seen in the previous graph, there is still a 40% of uncertainty regarding the cathode technology which will be developed in the continent. This is because certain companies (usually large ones such as Tesla or CATL) have

not specified which alternative or share of alternatives will they be developing in their plants.

To solve this uncertainty, a couple of scenarios have been added to the analysis to see the difference between them, and to study the different realities that the market could face in the following years. Both the percentage of each technology and the value of the market has been calculated for each scenario.

The first scenario shows each technology´s market shares in the case that the "unknown" share previously seen would be distributed as a 50% LFP and 50% NMC. This would cause the market to show a 27% of LFP share at the end of the decade, with a 12% increase from 2023.
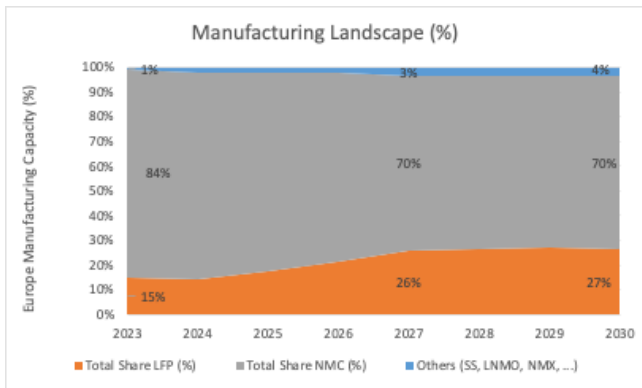

Figure 4: Manufacturing landscape for the rest of the decade in LFP optimistic scenario

The second scenario shows a reality in which NMC would take the lead. In this case, the distribution would be 80% NMC and 20% LFP. It is shown to see what an LFP-pessimistic scenario would look like. Still, as different CEOs of this companies whose production is "unknown" have stated their interest in LFP, this scenario is less probable.
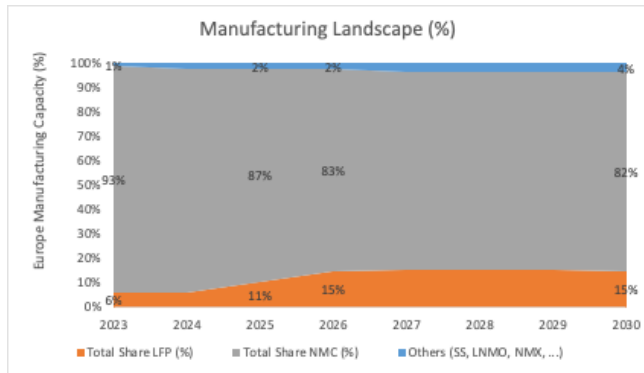

Figure 5: Manufacturing landscape for the rest of the decade in NMC optimistic scenario

Furthermore, it is also important to note that there is still an increase in the LFP market share through the years, while the

final share reaches ta 15% by 2023, increasing in 9% from 2023.

Valor LFP (€/kWh)	Valor NMC (€/kWh)
65	94

Table 1: Sale price of LFP and NMC

Considering the different values of the batteries depending on the technology, a change of 1 GWh in the market share from one technology to the other would cause a (94-65) * 1,000,000 = 29 M€ increase in the value of the market.

II. FINANCIAL ANALYSIS

In this section of the project, a financial analysis of one specific plant has been carried on showing the order of magnitude of the financial parameters that a project of this kind would have. The selected plant is the one located in the town of Sagunto, in Valencia, Spain. It has been chosen as the production capacity, technology, and initial investment of the plant have been specified by the company. The variables to take into consideration for the study are the following ones.

Parameter	Value
Average annual inflation	3%
Cathode technology	LFP
Sale Price of LFP	65 €/kWh
Annual reduction of the sale price	2%
Net margin of sales	8%
Factory output	40 GWh
Initial investment	4500 M€

Table 2: Variables to consider for the analysis.

With these variables, the financial analysis has been carried on, calculating the NPV, the IRR, and the Payback Period. It is important to note that the inflation is needed to calculate the NPV, the Gigafactory output and the sale price of LFP and the reduction of the price is needed to calculate the value for the sales, the net margin of the sales to calculate the net annual cash flows of the plant. With these parameters, the following results have been obtained for a project duration of 30 years (2023-2053).

Index	Value
NPV	649 M€
IRR	2,9 %
Payback Period	20 years

Table 3: Results of the analysis

This means that the project is profitable in a duration of 30 yeas, that the value of inflation that would make the NPV

equal zero would be 2,9%, and that the return of the investment without considering the present value of the money would be achieved in 20 years.

IV. DATABASE DEVELOPMENT

In this section of the project the data base will be developed. To do this, a logical relational database schema is first created with primary and foreign keys that uniquely identify the different table entries. Subsequently, the database is created in SQL with the corresponding tables and the mentioned logical relationships, to later fill it in, with real data in some of the cases, fictitious in others, and simply null in others. Once the database is filled with records, queries can be made that would be useful to get a first idea of the market and its reality. From there, this database could be used to develop algorithms, analyses, studies, or models. Everything has been programmed in SQL The steps taken to created, fill, and perform queries to the database are explained below.

ii) LOGICAL SCHEME

The first part of the Database creation corresponds to the logical scheme or diagram. 6 tables have been created. The purpose of each table is explained below.
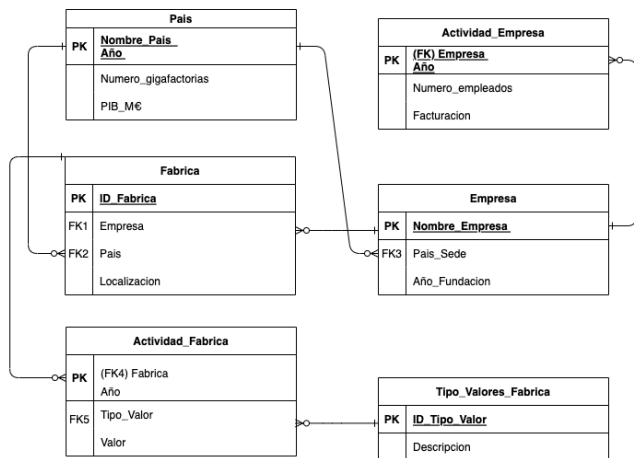

Figure 6: Logical Scheme of the Database

- **Pais.** In this table the name of the country and the year are stored as primary keys, while the purpose of the table is to register some of the stationary data of the countries. The values registered would be the Number of Gigafactories and PIB of each year in each country, but other additional columns could be added, depending on the interest.

- **Fabrica.** This table stores the non-stational information of a specific factory, such as the company which owns it, the country in which is located, and the city. The primary key is an ID of the factory which uniquely identifies it from others.

- **Actividad_Fabrica.** This table stores the stationary information of the factory. It receives the key of the factory ID, which conforms a primary key of this table along with the column "Año" and the column "Tipo_Valor". The value stored can be of a type which is specified in the table Tipo_Valores_Fabrica

- **Tipo_Valores_Fabrica.** This table is just a register of what each ID of type of value (ID_Tipo_Valor) means (descripcion). This ID is then passed to the table Actividad_Fabrica.

- **Empresa.** Table which stores the non-stationary information of a certain company such as the foundation year its the headquearter´s country location (assuming it does not change).

- **Actividad_Empresa.** Analog to Actividad_Fabrica, this table stores some stationary information of the companies. The primary key is made by the name of the company and the year, and the information stored is the number of employees and the sales of the year.

The type of variables of the Database is listed below.

Variable	Type of Variable
ID_Fabrica	INT
Nombre_Pais	VARCHAR
Año	INT
Valor	INT
ID_Tipo_Valor	INT
Descripcion	VARCHAR
Nombre_Empresa	VARCHAR
Numero_Gigafactorias	INT
Facturacion	INT
Localizacion	VARCHAR
PIB	INT
Numero_Empleados	INT

Table 4: Type of variables of the Database

iii) DATABASE CREATION

In this section of the study the database will be programmed. The whole code is added in the Appendix I. Therefore, only an example of it will be added in this section to explain what each function does and who are the relations created., as shown below. It is also important to note that the very first step when creating a Database is creating and naming the database itself, and "using" it, as shown in the first two lines of code. Once the Database is created, the specific tables can be added.

```sql
CREATE DATABASE TFM;
USE TFM;
```

```
CREATE TABLE Actividad Fabrica (
  Fabrica INT,
  Año INT,
  Tipo Valor INT,
  Valor INT,
  PRIMARY KEY (Fabrica, Año, Tipo Valor),
  FOREIGN KEY (Fabrica) REFERENCES
Fabrica(ID_Fabrica),
  FOREIGN KEY (Tipo_Valor) REFERENCES
Tipo Valores Fabrica(ID Tipo Valor Fabrica)
);
```

This is an example of the creation of the table Actividad_Fabrica, which, as explained before, registers the non-stationary data of the factories. The first step is the command create, which is preceded by the name of the table. Then, all the entrances (columns) of the table, and their names, are added. As it can be seen it is important to add the type of variable in question as well. The 3 last steps refer to the primary key and foreign keys statement. The primary key one selects both Fabrica, Año, and Tipo_Valor as the primary key of the table, as the sum of these 3 columns are uniquely different from the rest. In addition, the foreign keys of the ID of the factory and the type of value are added from the respective tables.

iv) FILLING THE DATABASE

In this step, the Database is filled. As it has been done in the previous section, a part of the code used to fill the database will be explained. This case slightly simpler as the relations and keys are already created. It is therefore only necessary to fill the gaps with the same number of columns, and with the data type specified in Table 1. The INSERT function follows the structure shown in the following lines of code.

```
INSERT INTO Empresa (Nombre_Empresa,
Pais_Sede, Año_Fundacion) VALUES
  ('Phi4Tech','España', 2018),
  ('Envision AESC','Japon', 2009),
  ('BasqueVolt','España', 2021),
  ('Volkswagen','Alemania', 1937),
  ('ACC','Francia', 2019),
  ('Verkor','Francia', 2020);
```

v) QUERIES

In this section of the study, certain queries will be performed to see the data that has been filed into the Database. First of all, generic queries to see the whole tables are performed. For this aim, a SELECT * FROM Name_of_table statement is executed, as seen in the following example.

```
SELECT * FROM Pais;

SELECT * FROM Pais WHERE
Numero_gigafactorias >= 3;
```

Then, some queries including conditional clauses are added. In the following query, for example, from the table Empresa, the condition assures that only the companies whose headquarters are in Germany (Alemania), are shown.

```
SELECT * FROM Empresa WHERE
Pais_Sede LIKE 'Alemania';
```

The following condition is similar than the last one, but numeric. In this case only the companies which have a number of employees greater than 2000 will be shown.

```
SELECT * FROM Actividad Empresa
WHERE Num_empleados > 2000 AND año
LIKE 2023;
```

Now, two more complex queries will be explained. First, a query to see the different factories along with certain information of their activity and the information of the type of value of the activity of the factory will be displayed. For this aim, a double JOIN function will be required, as it is necessary to join three tables connected by keys. For this aim, it is first necessary to JOIN two of them, and then the third one. As it can be seen, the tables Fabrica and Actividad_Fabrica are the first ones joined, followed by the table Tipo_Valores_Fabrica. The key which connects Fabrica with Actividad_Fabrica is the primary key of Fabrica named ID_Fabrica, while the key which connects Actividad_Fabrica with Tipo_Valores_Fabrica is the primary key of Tipo_Valores_fabrica, named ID_Tipo_Valor_Fabrica. It is also important to note that the in first step the table Tipo_Valores_Fabrica the ID which corresponds to the production of NMC was extracted.

```
SELECT Empresa, Localizacion, Pais,
Descripcion, Valor, Año FROM
(SELECT * FROM
(SELECT * FROM Actividad_Fabrica
WHERE Tipo_valor =
(SELECT ID_Tipo_Valor_Fabrica FROM
Tipo_Valores_Fabrica WHERE
Tipo_Valores_Fabrica.Descripcion
LIKE 'Produccion NMC (GWh)')) AS
table_aux1
JOIN Fabrica ON table_aux1.Fabrica =
Fabrica.ID_Fabrica) AS table_aux2
JOIN Tipo_Valores_Fabrica ON
table_aux2.Tipo_Valor =
Tipo_Valores_Fabrica.ID_Tipo_Valor_F
abrica;
```

After this query, one last and simpler one is executed. In this case, a simple JOIN function is used to see the information of certain columns from the factories along with the corresponding company which owns the factory. It is

important to note that the derived table has to be named for the program to be correctly executed. In this case, it has been named as table_aux3.

```
SELECT Empresa, Localizacion, Pais,
Pais_Sede, Año_Fundacion FROM
(SELECT * FROM Fabrica JOIN
Empresa ON Fabrica.Empresa =
Empresa.Nombre_Empresa) AS
table_aux3;
```

V. RESULTS

In this section, the results from the different queries executed will be shown and explained.

First, it will be shown the result from the query to see the whole table Empresa to check that all the entrances previously indicated are in the table. As it was expected, all the companies previously written in the last section can be seen in the table.

	Nombre_Empresa	Pais_Sede	Año_Fundacion
▶	ACC	Francia	2019
	BasqueVolt	España	2021
	Envision AESC	Japon	2009
	Phi4Tech	España	2018
	Verkor	Francia	2020
	Volkswagen	Alemania	1937

The results of the second, third and fourth queries will be shown without further explanation.

	Nombre_Pais	Año	Numero_gigafactorias	PIB_M€
▶	Alemania	2023	3	4260000
	Hungria	2023	3	182000

	Nombre_Empresa	Pais_Sede	Año_Fundacion
▶	Volkswagen	Alemania	1937

	Empresa	Año	Num_empleados	Facturacion
▶	ACC	2023	2500	NULL
	Envision AESC	2023	7000	NULL
	Volkswagen	2023	626715	NULL

The fifth query deserves further explanation. As it can be seen, only the selected columns are shown. The key which connects the table Fabrica with Actividad_Fabrica is the ID of the factory, which has not even been selected to be shown in the display. The key which connects the table Actividad_Fabrica with Tipo_Valores_Fabrica is the Id of the type of value (ID_Tipo_Valor_Fabrica). As well, it has not been shown. The query responds to the aim of wanting to see the information of the name of the company which

operates the factory, the location of the factory (with city name and country), and the GWh produced through the years of a specific technology.

	Empresa	Localizacion	Pais	Descripcion	Valor	Año
▶	BasqueVolt	Vitoria	España	Produccion NMC (GWh)	13	2028
	ACC	Billy-Berclau	Francia	Produccion NMC (GWh)	24	2028
	Envision AESC	Douai	Francia	Produccion NMC (GWh)	18	2028
	Verkor	Dunkirk	Francia	Produccion NMC (GWh)	35	2028

Finally, the result of the query which aims to merge both the data of the factories and the Companies together is shown below. As it can be seen, only the selected columns are shown.

	Empresa	Localizacion	Pais	Pais_Sede	Año_Fundacion
▶	ACC	Billy-Berclau	Francia	Francia	2019
	BasqueVolt	Vitoria	España	España	2021
	Envision AESC	Navalmoral de la Mata	España	Japon	2009
	Envision AESC	Douai	Francia	Japon	2009
	Phi4Tech	Badajoz	España	España	2018
	Verkor	Dunkirk	Francia	Francia	2020
	Volkswagen	Sagunto	Sagunto spaña	Alemania	1937

VI. CONCLUSIONS

The following conclusions can be extracted from the paper:

- A relational Database is needed to face the lack of unification when regarding registers of Gigafactories thought Europe.

- These kinds of projects have a Payback Period of about 20 years and a NPV positive, the profitability is high although they face some risks like inflation or external competitors.

- There is still a lot of uncertainty regarding which technology will lead the market.

- There is still a lot of work to do regarding models and algorithms which would give a better understanding of the market. The first step was to develop a Database.

- LFP cathode chemistry technology will increase its market share even in the most pessimistic scenario.

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APPENDIX I – CODE OF THE DATABASE

```sql
CREATE DATABASE TFM;
USE TFM;

CREATE TABLE Pais (
  Nombre_Pais VARCHAR(50),
  Año INT,
  Numero_gigafactorias INT,
  PIB_M€ INT,
  PRIMARY KEY (Nombre_Pais, Año)
);

CREATE TABLE Empresa (
  Nombre_Empresa VARCHAR(50) PRIMARY
KEY,
  Pais_Sede VARCHAR(50),
  Año_Fundacion INT,
  FOREIGN KEY (Pais_Sede) REFERENCES
Pais(Nombre_Pais)
);

CREATE TABLE Actividad_Empresa (
  Empresa VARCHAR(50),
  Año INT,
  Num_empleados INT,
  Facturacion INT,
  PRIMARY KEY (Empresa, Año),
  FOREIGN KEY (Empresa) REFERENCES
Empresa(Nombre_Empresa)
);

CREATE TABLE Fabrica (
  ID_Fabrica INT PRIMARY KEY,
  Empresa VARCHAR(50),
  Localizacion VARCHAR(50),
  Pais VARCHAR(50),
  FOREIGN KEY (Empresa) REFERENCES
Empresa(Nombre_Empresa),
  FOREIGN KEY (Pais) REFERENCES
Pais(Nombre_Pais)
);

CREATE TABLE Tipo_Valores_Fabrica (
  ID_Tipo_Valor_Fabrica INT PRIMARY KEY,
  Descripcion VARCHAR(50)
);

CREATE TABLE Actividad_Fabrica (
  Fabrica INT,
  Año INT,
  Tipo_Valor INT,
  Valor INT,
  PRIMARY KEY (Fabrica, Año,
Tipo_Valor),
  FOREIGN KEY (Fabrica) REFERENCES
Fabrica(ID_Fabrica),
```

```sql
  FOREIGN KEY (Tipo_Valor) REFERENCES
Tipo_Valores_Fabrica(ID_Tipo_Valor_Fabri
ca)
);
```

```sql
INSERT INTO Pais (Nombre_Pais, Año,
Numero_gigafactorias, PIB_M€) VALUES
  ('España', 2023, 1, 1427000),
  ('Francia', 2023, 0, 2958000),
  ('Italia', 2023, 1, 2108000),
  ('Grecia', 2023, 1, 214000),
  ('Serbia', 2023, 0, 63000),
  ('Suecia', 2023, 1, 635000),
  ('Eslovaquia', 2023, 0, 116000),
  ('Hungria', 2023, 3, 182000),
  ('Polonia', 2023, 1, 680000),
  ('Noruega', 2023, 0, 428000),
  ('Alemania', 2023, 3, 4260000),
  ('Japon', 2023, null, 4941000),
  ('China', 2023, null, 17730000);

INSERT INTO Empresa (Nombre_Empresa,
Pais_Sede, Año_Fundacion) VALUES
  ('Phi4Tech','España', 2018),
  ('Envision AESC','Japon', 2009),
  ('BasqueVolt','España', 2021),
  ('Volkswagen','Alemania', 1937),
  ('ACC','Francia', 2019),
  ('Verkor','Francia', 2020);

INSERT INTO Actividad_Empresa
(Empresa, Año, Num_empleados,
Facturacion) VALUES
  ('Phi4Tech', 2023, 49, null),
  ('Envision AESC', 2023, 7000,
null),
  ('BasqueVolt', 2023, 100, null),
  ('Volkswagen', 2023, 626715,
null),
  ('ACC', 2023, 2500, null),
  ('Verkor', 2023, 0, null);

INSERT INTO Fabrica (ID_Fabrica,
Empresa, Localizacion, Pais) VALUES
  (1, 'Phi4Tech', 'Badajoz',
'España'),
  (2, 'Envision AESC', 'Navalmoral
de la Mata', 'España'),
  (3, 'BasqueVolt', 'Vitoria',
'España'),
  (4, 'Volkswagen', 'Sagunto',
'España'),
  (5, 'ACC', 'Billy-Berclau',
'Francia'),
  (6, 'Envision AESC', 'Douai',
'Francia'),
```

```sql
    (7, 'Verkor', 'Dunkirk',
'Francia');

INSERT INTO Tipo_Valores_Fabrica
(ID_Tipo_Valor_Fabrica, Descripcion)
VALUES
    (1, 'Produccion LFP (GWh)'),
    (2, 'Produccion NMC (GWh)'),
    (3, 'Produccion Others (GWh)'),
    (4, 'Produccion UNKNOWN (GWh)'),
    (5, 'Capacidad Fabrica (GWh)');

INSERT INTO Actividad_Fabrica
(Fabrica, Año, Tipo_Valor, Valor)
VALUES
    (1, 2028, 3, 10),
    (2, 2028, 4, 20),
    (3, 2028, 2, 13),
    (4, 2028, 1, 40),
    (5, 2028, 2, 24),
    (6, 2028, 2, 18),
    (7, 2028, 2, 35);
```

```sql
SELECT * FROM Pais;
SELECT * FROM Empresa;
SELECT * FROM Actividad_Empresa;
SELECT * FROM Fabrica;
SELECT * FROM Tipo_Valores_Fabrica;
SELECT * FROM Actividad_Fabrica;

SELECT * FROM Pais; /*WHERE
Nombre_Pais LIKE 'España';*/
SELECT * FROM Pais WHERE
Numero_gigafactorias >= 3;

SELECT * FROM Empresa WHERE
Pais_Sede LIKE 'Alemania';

SELECT * FROM Actividad_Empresa
WHERE Empresa LIKE 'Phi4Tech' AND
año LIKE 2023;

SELECT * FROM Actividad_Empresa
WHERE Num_empleados > 2000 AND año
LIKE 2023;

SELECT * FROM Fabrica WHERE Pais
LIKE 'Francia';

SELECT Empresa, Localizacion, Pais,
Descripcion, Valor, Año FROM
(SELECT * FROM
(SELECT * FROM Actividad_Fabrica
WHERE Tipo_valor =
(SELECT ID_Tipo_Valor_Fabrica FROM
Tipo_Valores_Fabrica WHERE
Tipo_Valores_Fabrica.Descripcion
```

```sql
LIKE 'Produccion NMC (GWh)')) AS
table_aux1
JOIN Fabrica ON table_aux1.Fabrica =
Fabrica.ID_Fabrica) AS table_aux2
JOIN Tipo_Valores_Fabrica ON
table_aux2.Tipo_Valor =
Tipo_Valores_Fabrica.ID_Tipo_Valor_F
abrica;

SELECT Empresa, Localizacion, Pais,
Pais_Sede, Año_Fundacion FROM
(SELECT * FROM Fabrica JOIN
Empresa ON Fabrica.Empresa =
Empresa.Nombre_Empresa) AS
table_aux3;
```