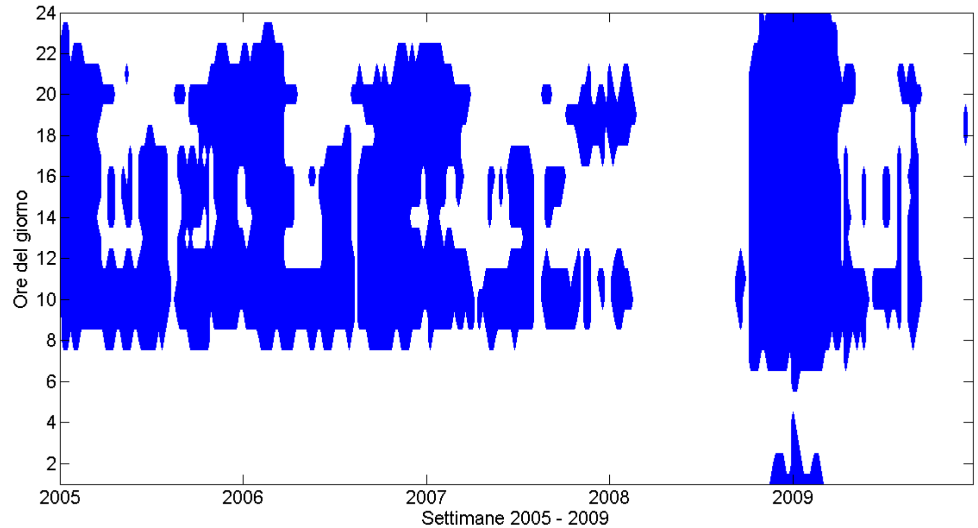

Process retrofitting

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Process retrofitting

- **Retrofitting** refers to the addition of new technology or features to older systems.
- **Process retrofitting** consists in **adding/modifying/revisiting/revising** an existing process by introducing alternative ways of producing or exploiting some production issues to **enhance its operation, improve its efficiency, increase its economic appeal, reduce its impact, increase its sustainability, improve its flexibility**.
- Retrofitting an existing industrial plant, by using the latest technology, usually allows **increasing the production capacity** and **reducing the limitations** and **inefficiencies** that were intrinsic to the original design.
- After retrofitting, the plant operation is usually more stable and can be operated more easily and with higher efficiency.
- **Some examples**: new profiles in the blades of wind turbines, new heat exchangers with improved efficiency, lower emission engines, more resistant building materials, more efficient mixers and separators, …

Retrofitting the HDA process

- The design procedure should answer the following questions:
  - What are the most important solutions to increase the productivity of new plants or enhance the efficiency of existing ones?
  - What are the **process alternatives** (*i.e.* **Process Subsections**, **PS**s) capable of retrofitting the existing plant?
  - Is the PS a viable solution to cope with plant retrofitting?
  - Is the PS economically viable in terms of revenues, installation costs, and working capital?
  - If the PS is the optimal solution, how long should it run?
  - Are there any suitable time intervals in the day, week, season, and even year when the designed PS should be run?
  - Are there distinct PSs that should be operated in an alternating way by switching between them?

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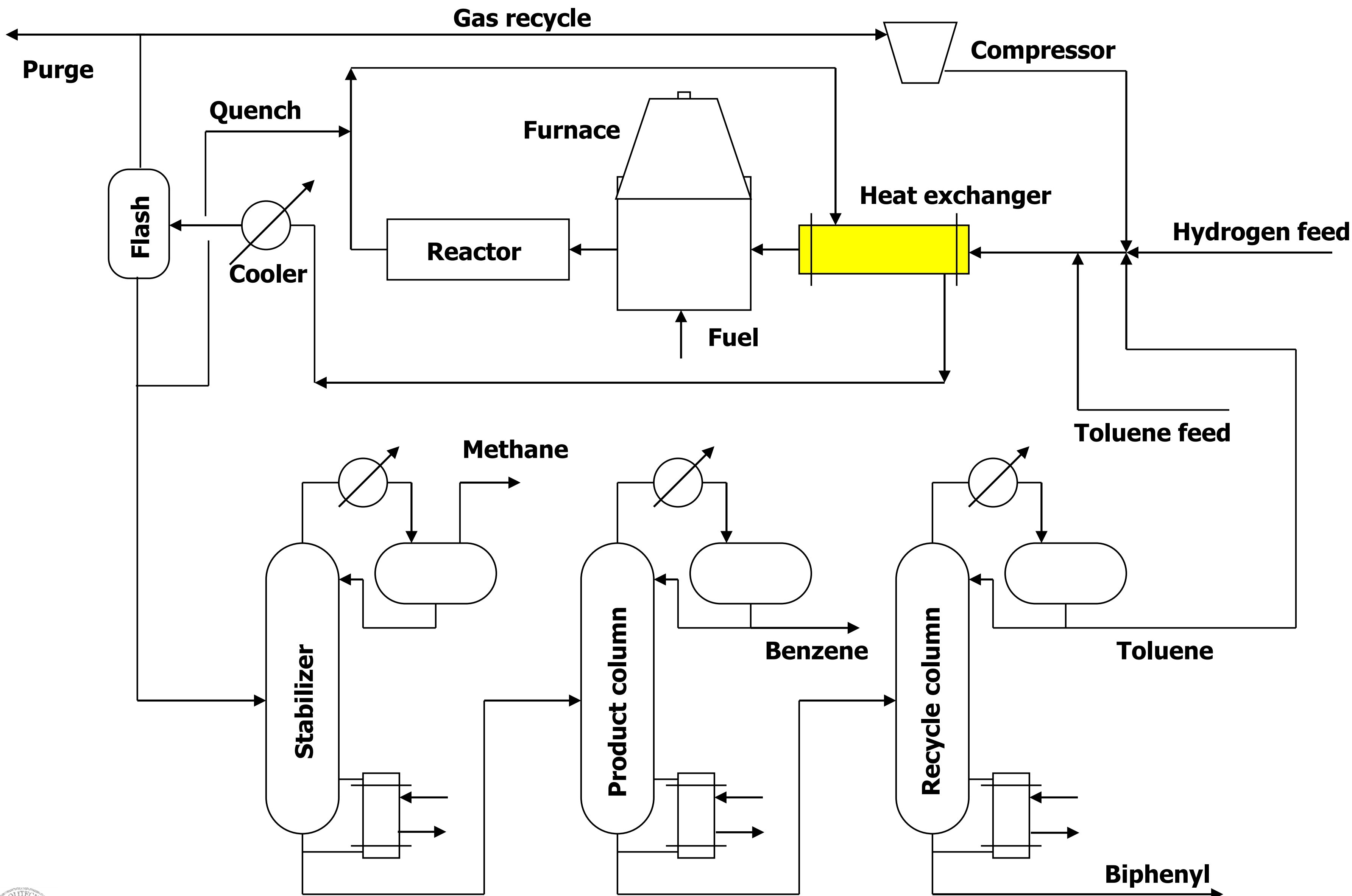
A case study

- The proposed case-study allows tackling the **retrofitting** of a well-known process where the design activity is supported by the methodological approach to **dynamic conceptual design**.
- We focus on the hydrodealkylation process, HDA, that converts toluene to benzene.
- By observing the HDA process we can highlight a significant enthalpic content of the outlet stream from the reactor. Such stream is quenched to block any further side conversion of toluene to biphenyl and its enthalpic content is exploited to preheat the inlet stream to the reaction section (although it is not sufficient and some further heating is provided in the furnace to comply with the process specification).
- The questions are:
  - **is it possible to exploit the enthalpic content of the reactor outlet by a different equipment setup?**
  - **are there any process units that could extract more value from the reactor outlet stream?**

The Feed-Effluent Heat Exchanger

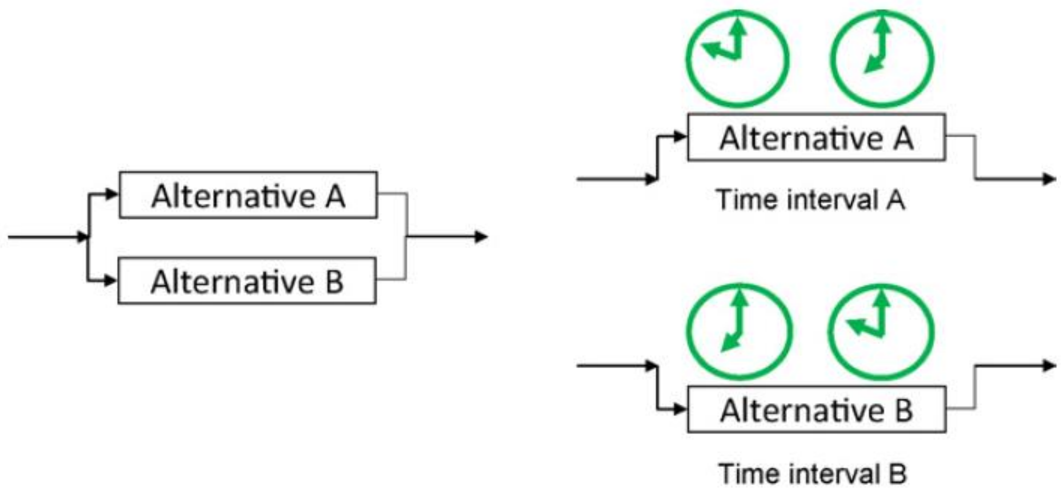


Retrofitting the HDA process

- Some hints to the process retrofitting deal with a better exploitation of the energy content of the outlet stream from the reactor.
- Is it physically possible and economically viable to produce electric energy from the steam obtained by recovering the outlet enthalpic flux from the reactor?
- Is a power generation subsection feasible?
- We define the **energy production section**: **EPS**. It is the plant section where electric energy may be produced. Consequently, if we install the EPS it will also be necessary to preheat the inlet stream to the reactor by means of additional heat provided by the furnace.
- We have two alternatives with a further branch:
  - **Install the EPS**
    - Run the EPS continuously (*i.e.* 24/7)
    - Run the EPS discontinuously when its revenues are higher than the additional expenditures due to the increased use of the furnace (*i.e.* a portion of the daily 24 hours)
  - **Do not install the EPS**

Retrofitting the HDA process

- In case of discontinuous operation of the **EPS** and **FEHE** alternatives, we are in front of a process alternative that could be operated at specific time intervals:



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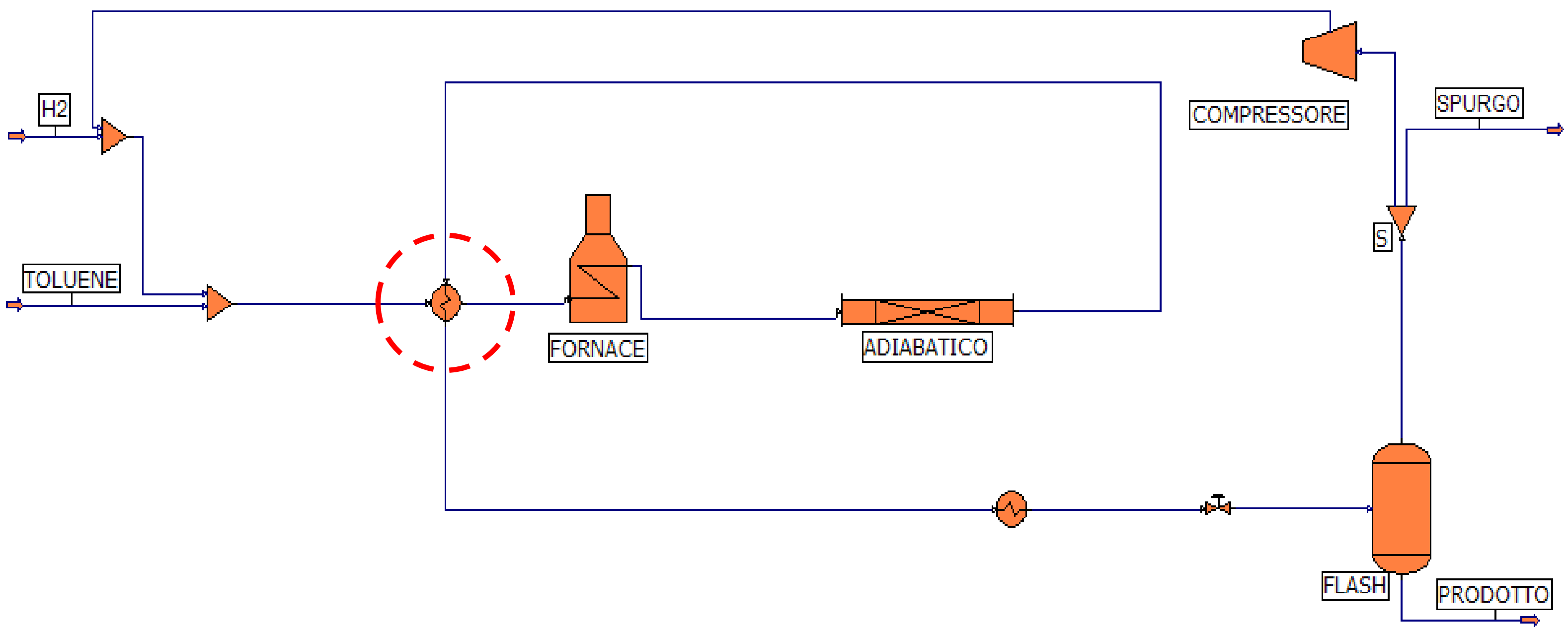
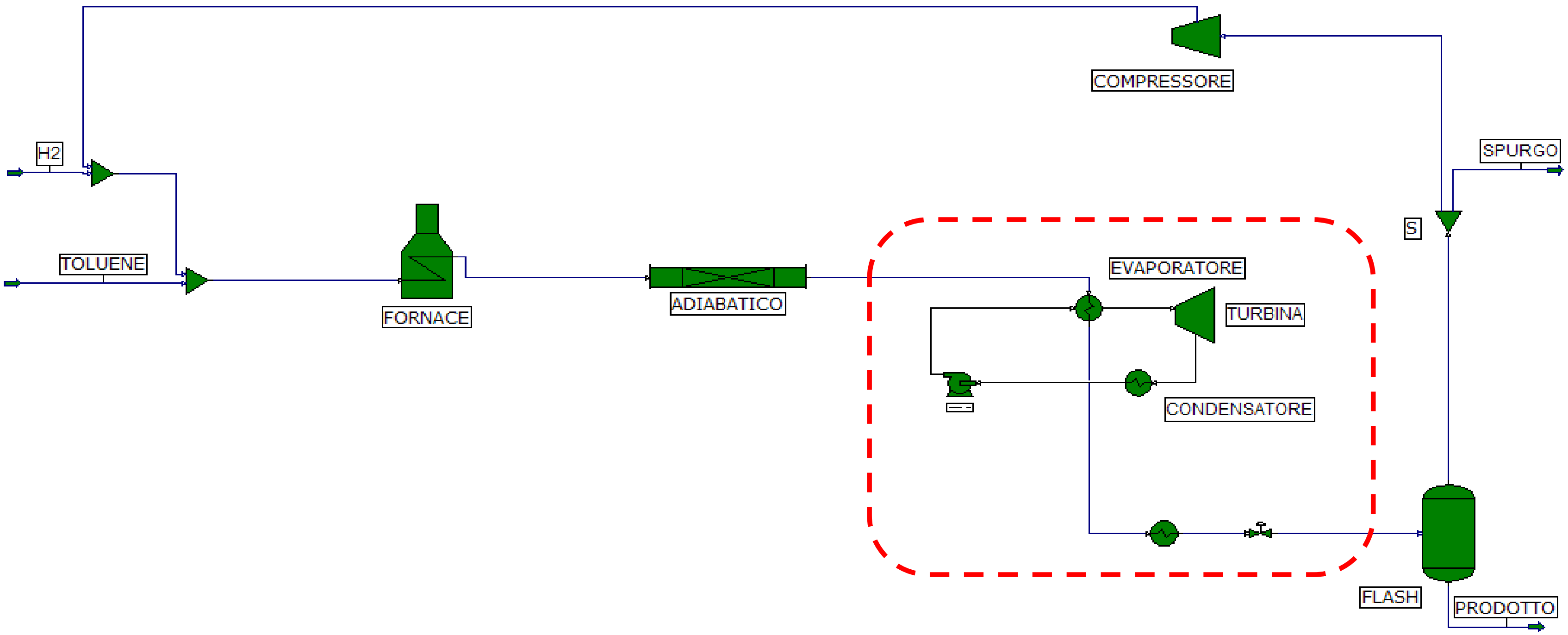
Retrofitting the HDA process

- The **alternating operation** of FEHE and EPS requires switching between the exploitation of the energy flux from the reactor to preheat its inlet stream through the **FEHE**:



Retrofitting the HDA process

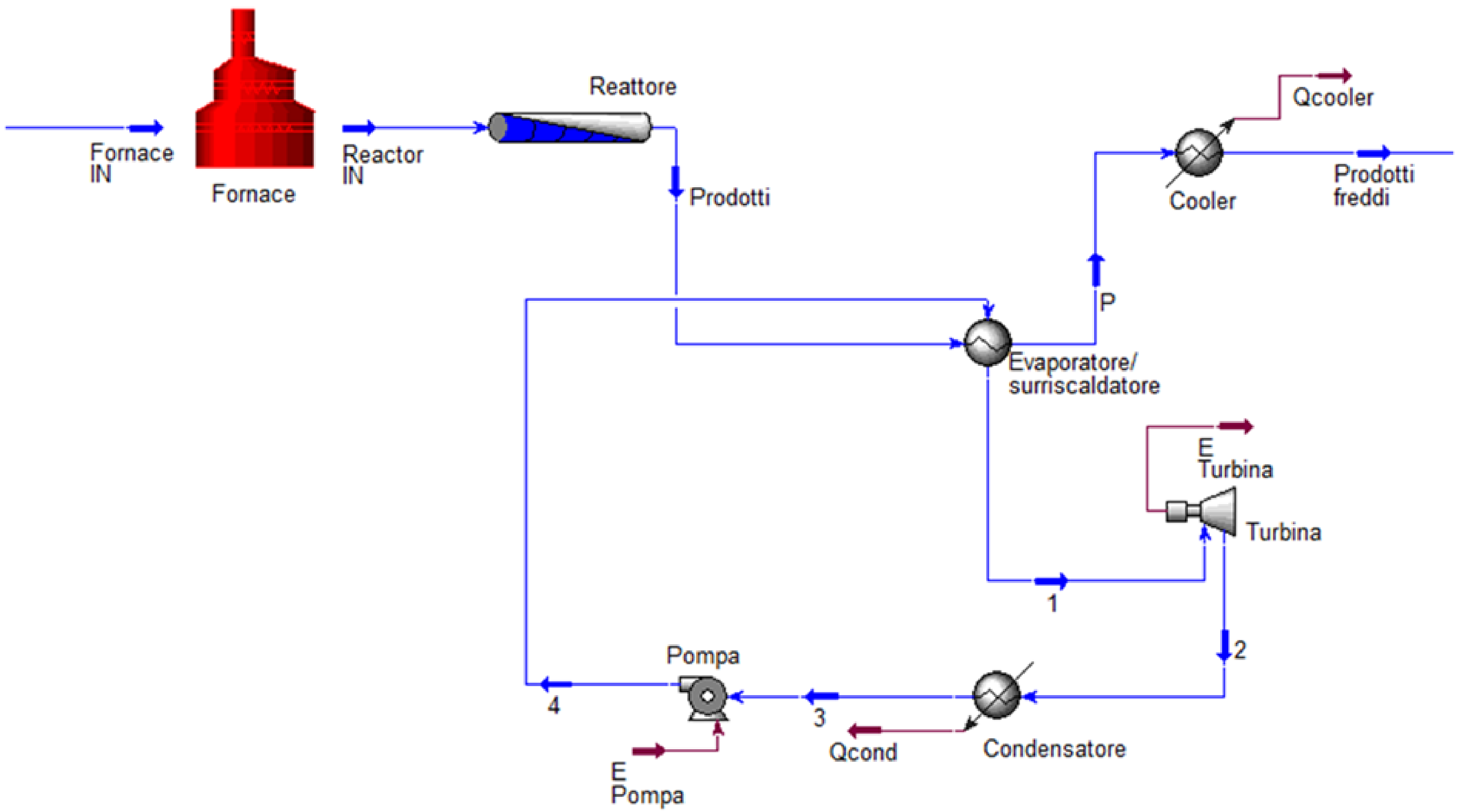
- and operating the **EPS** by bypassing the FEHE:



- We can suppose that the EPS is operated when the revenues from selling the electric energy are high, whilst it could be more economically viable operating the FEHE when the price of electric energy is low, thus saving money by burning a smaller amount of fuel in the furnace.

Retrofitting the HDA process

- This is a more in depth detail of the HDA plant when the EPS is operated:



Retrofitting the HDA process

- The EPS layout calls for **new pieces of equipment** such as:
  - **Evaporator/superheater**
  - **Steam turbine**
  - **Steam condenser**
  - **Water recycle pump**
- These process units must be designed and economically assessed in terms of CAPEX and OPEX terms.
- The OPEX terms should also take into account the increased demand of energy required by the furnace to heat the inlet stream to the reaction section since, when the EPS is running, the contribution from the FEHE is missing (actually the FEHE is bypassed and in standby).

Retrofitting the HDA process

- The EPS design undergoes a rather simplified approach that does not go into the mechanical and electrical details (where <u>the support of both mechanical and electrical engineers is absolutely mandatory</u>).
- By assuming an overall thermodynamic efficiency of the EPS equal to 35% we can appraise the amount of electric energy produced as a function of the enthalpic flux of the outlet stream from the reactor.
- We get the following thermal and electrical powers of the EPS:

Evaporator	2.191E8 kJ/h
Turbine	0.767E8 kJ/h
Condenser	1.439E8 kJ/h
Water pump	0.015E8 kJ/h

Retrofitting the HDA process

- According to the previous estimates, we can determine that:
  - the turbine supplies an electric power of 21583 kW
  - the furnace consumes more fuel equal to a thermal power of 2.4344E8 kJ/h
- If we burn fuel oil in the furnace, whose price was modeled as a function of the CO quotation, we have the following properties:
  - Oil density: 900 kg/m^3
  - Heat of combustion: 40813 kJ/kg
- We can deduce that, when the EPS is running, there is an additional request of 5964 kg/h of burning oil to operate the furnace according to the specifications for the inlet stream to the reactor.
- **N.B.**: the additional amount of fuel oil to the furnace **could** lead to an increased capacity of that process unit, thus increasing its investment cost.

Economic assessment of the retrofitted HDA

- By using the simulated scenarios for the economic assessment of the conventional HDA plant we can determine the dynamic contribution of the **economic potential of EPS**:

$$Revenues_{k,i,j}\left[{}^{\$}\!/\!{}_{h}\right]=$$
$$=\max\left[0,\left\{C_{EE,k,i,j}\cdot\left(W_{turb}-W_{pump}\right)-C_{H_2O}\cdot F_{H_2O_{cond}}-C_{FuelOil,k,i}\cdot\left(F_{FuelOilEPS}-F_{FuelOilSTD}\right)\right\}\right]$$

$$IC_{tot}[\$]=IC_{turb}+IC_{evap}+IC_{cond}+IC_{pump}+\left(IC_{furnaceEPS}-IC_{furnaceSTD}\right)$$

$$DEP_{EPS,k}[\$]=\sum_{i=1}^{nWeeks}\left[\sum_{j=1}^{nHours}\left(Revenues_{k,i,j}\cdot nDaysPerWeek\right)\right]-IC_{tot}$$
$$\forall k=1,\ldots,nScenarios$$

Economic assessment of the retrofitted HDA

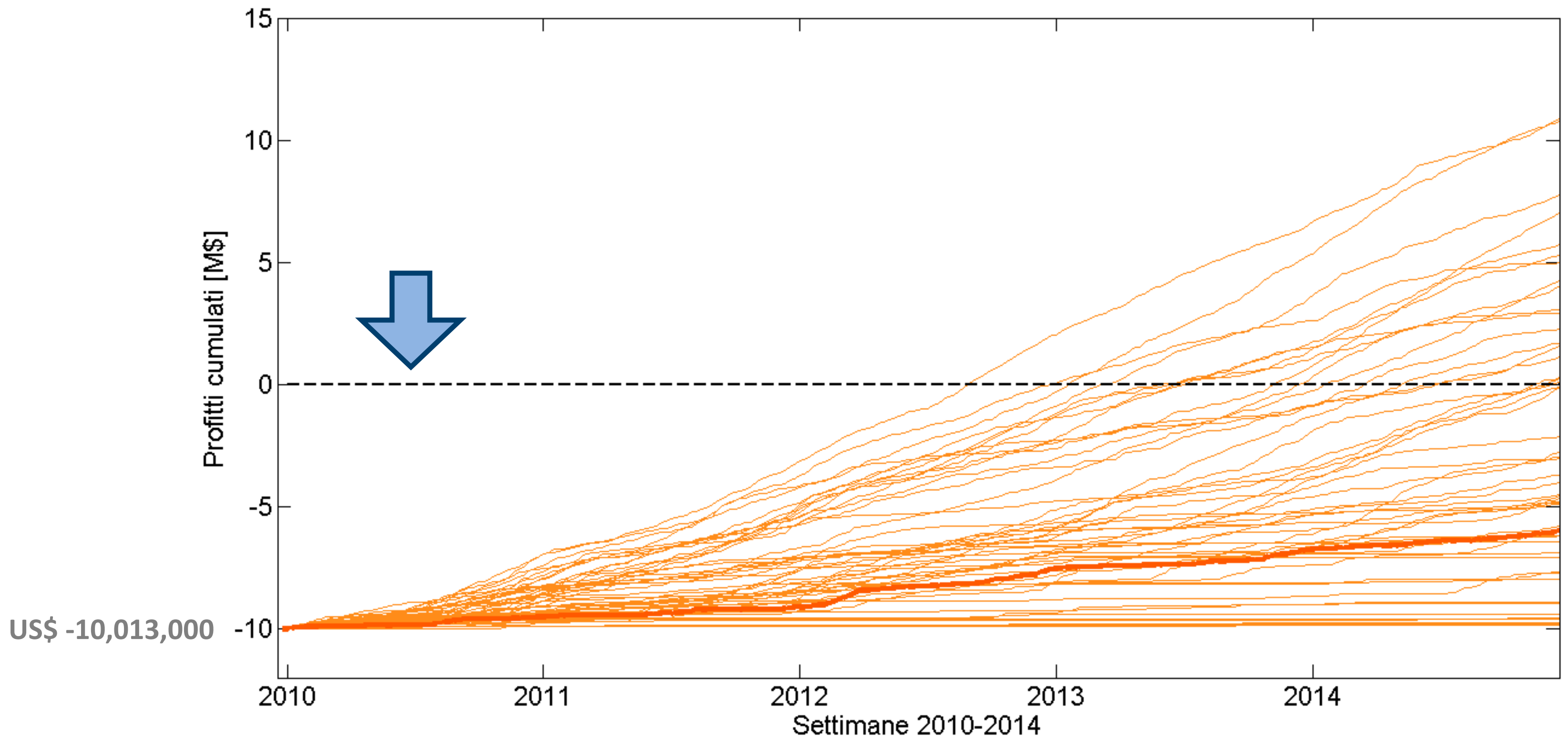
- Since the model of the CO quotation was developed on a weekly basis then the price of EE will be averaged on the same weekly basis for each of the 24 time bands of the day.
- **N.B.**: the EPS and STD subscripts for the $FuelOil$ and $Furnace$ contributions refer respectively to the different costs of the equipment and operating expenses either in presence or in absence of the EPS.
- **N.B.**: the investment/installation costs, IC, of the additional equipment for the EPS can be evaluated with the Guthrie's formulae (Guthrie, 1969).
- **N.B.**: the investment costs, IC, **are not annualized**. Conversely, they are considered as a whole since the very beginning of the EPS operation. By doing so, it is possible to determine the pay back period and the economic feasibility of the EPS.
- **N.B.**: the EPS $Revenues$, by formalizing the $\max$ function contribution, translate the decision to operate that plant section only when the profit is positive.

Economic assessment of the retrofitted HDA

- **N.B.**: the proposed economic assessment is quite simplified. No transients are taken into account when evaluating the DEP_{EPS}. The absence of transients assumes that the plant can instantaneously switch from the FEHE to the EPS layout and back. In addition, no investigation about mechanical and thermal stresses on the involved equipment (furnace refractory, furnace pipes, turbine shaft, turbine blades, FEHE, evaporator, superheater, condenser) has been performed.
- **N.B.**: the unavoidable transients produced by switching between the FEHE and EPS alternatives may also produce some off-specs on the production quality thus introducing further elements to be discussed and possibly quantified.

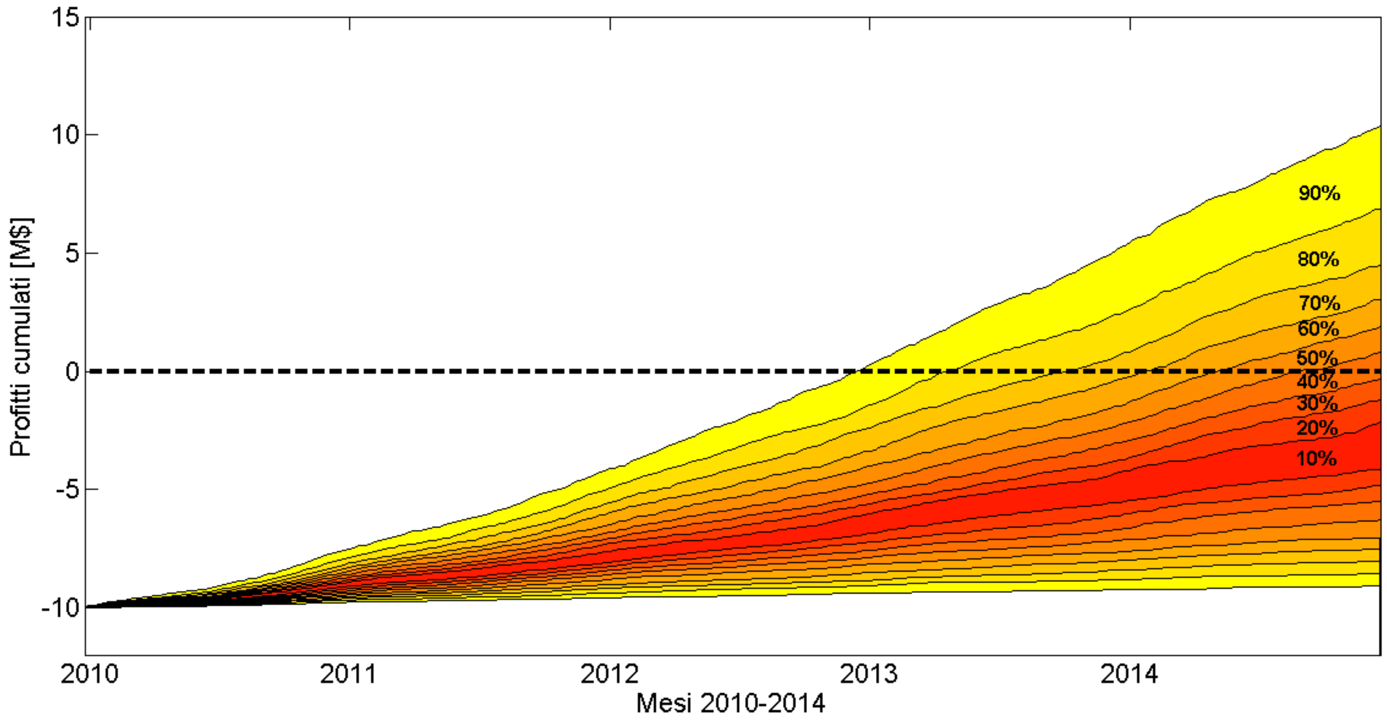
Economic assessment of the retrofitted HDA

- The cumulative revenues for 50 distinct scenarios show the following trend:



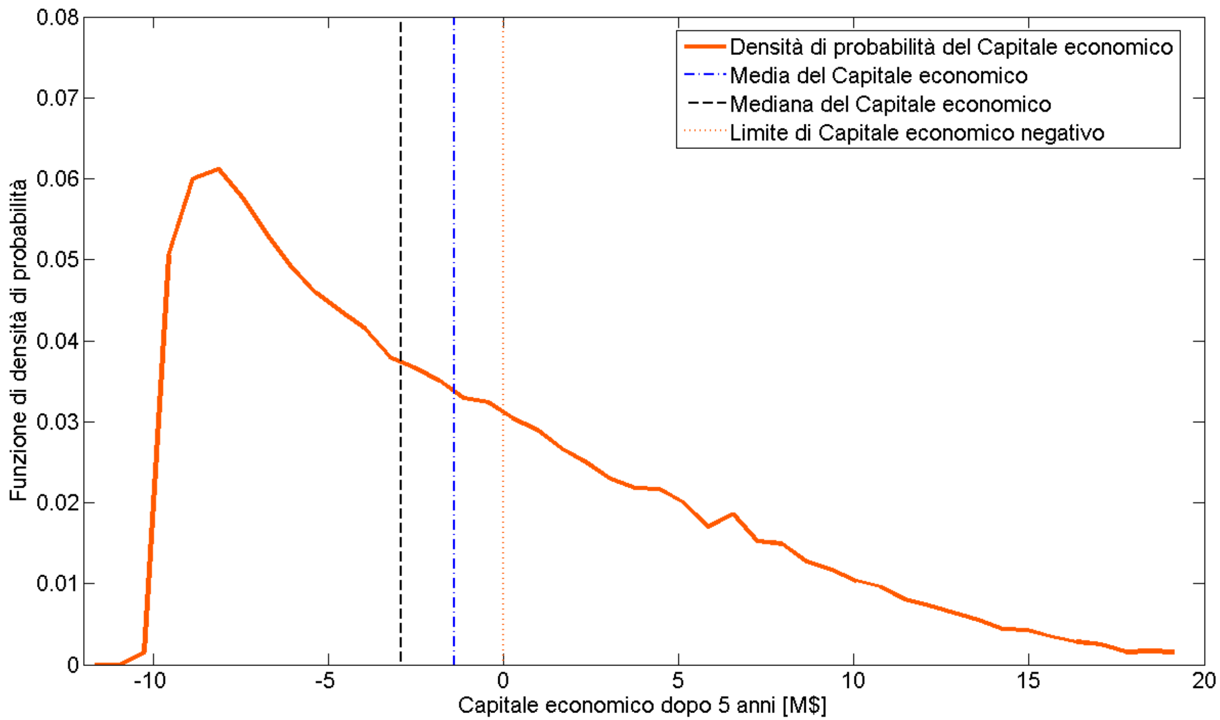
Economic assessment of the retrofitted HDA

- A five-year period is on average not sufficient to recover from the initial investment, as it is shown in the fan diagram reporting 3,000 distinct scenarios:



Economic assessment of the retrofitted HDA

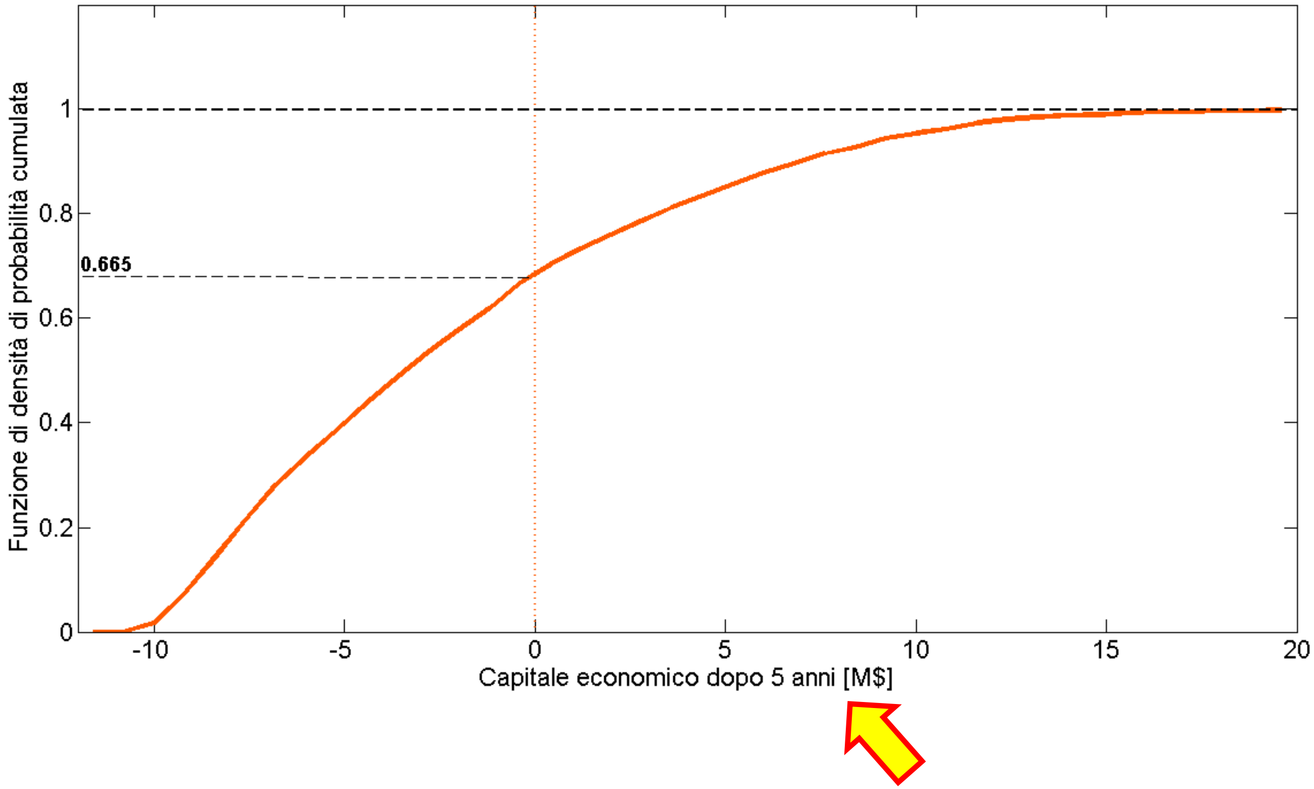
- … as also shown in the following diagram of the probability density function:



- Only 33% of the scenarios allow reaching the **break-even point** between the expenses and revenues over a **payback period** of five years.

Economic assessment of the retrofitted HDA

- Equally, the cumulative distribution of the probability function over the same five-year horizon shows that only 1/3 of the economic scenarios have a positive return from the initial capital investment of US$ 10,013,000, whilst 2/3 have a negative return.



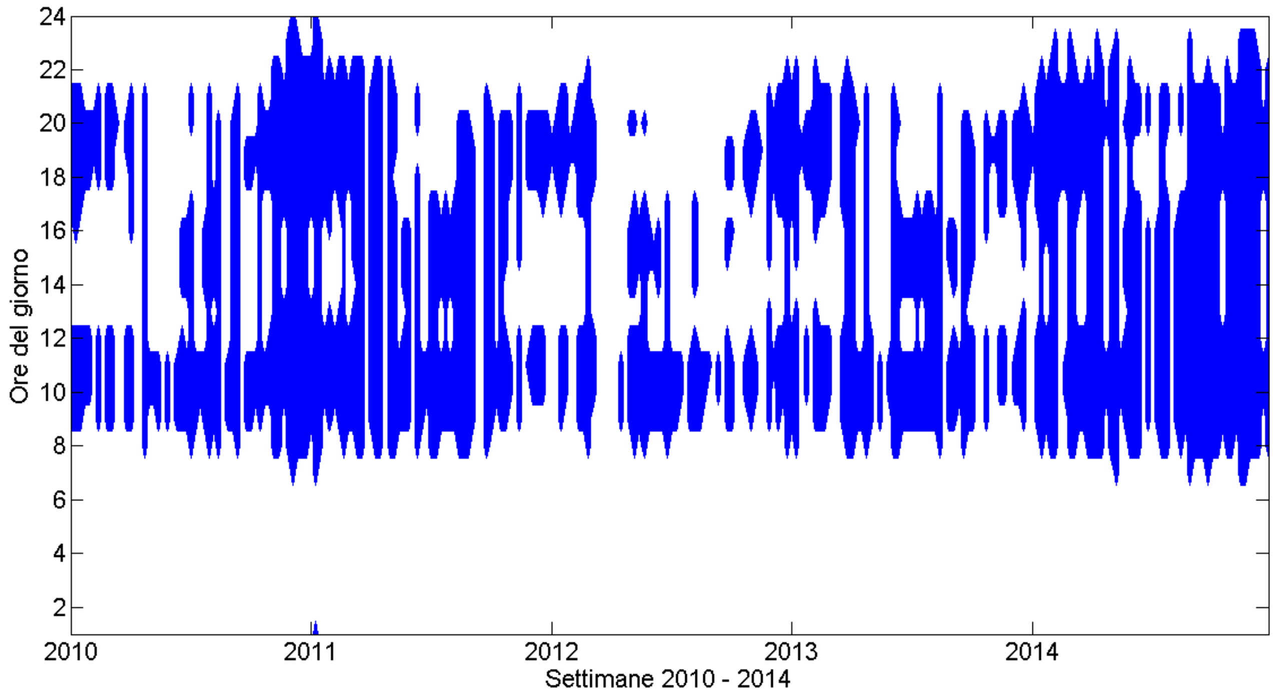
Economic assessment of the retrofitted HDA

- For longer time horizons the probability of **not** recovering from the investment decreases as shown in the following table:

5 years	66.5%
10 years	45.4%
15 years	27.5%
20 years	19.4%

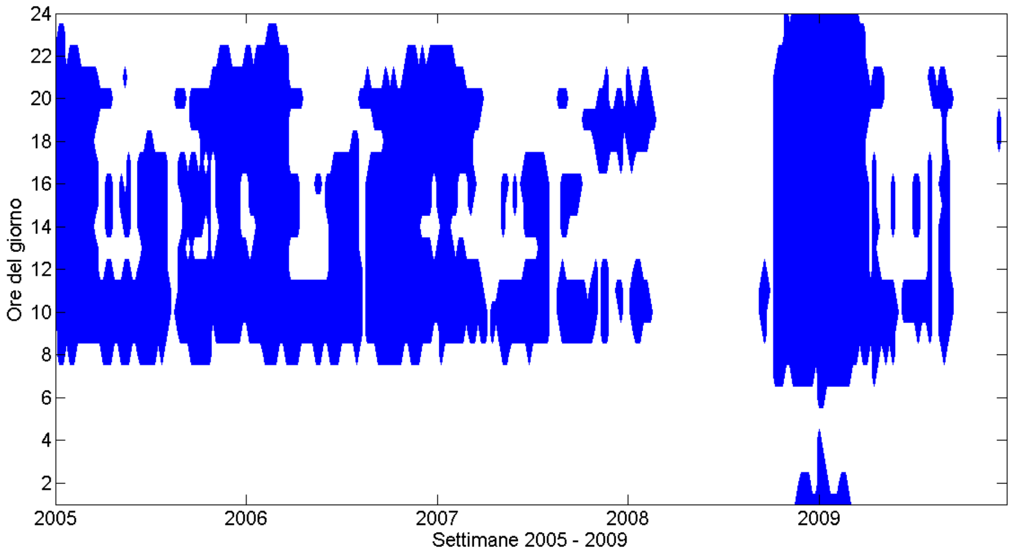
About switching on and off the EPS

- It is quite interesting to study the distribution of the hours in the day and of the days/weeks in the year when the EPS should be operated.
- By picking just <u>one **forecasting** economic scenario</u>, for the five-year period, we can observe how the EPS should be operated only at daylight (*i.e.* in the 8:00 am - 9:00 pm band).



About switching on and off the EPS

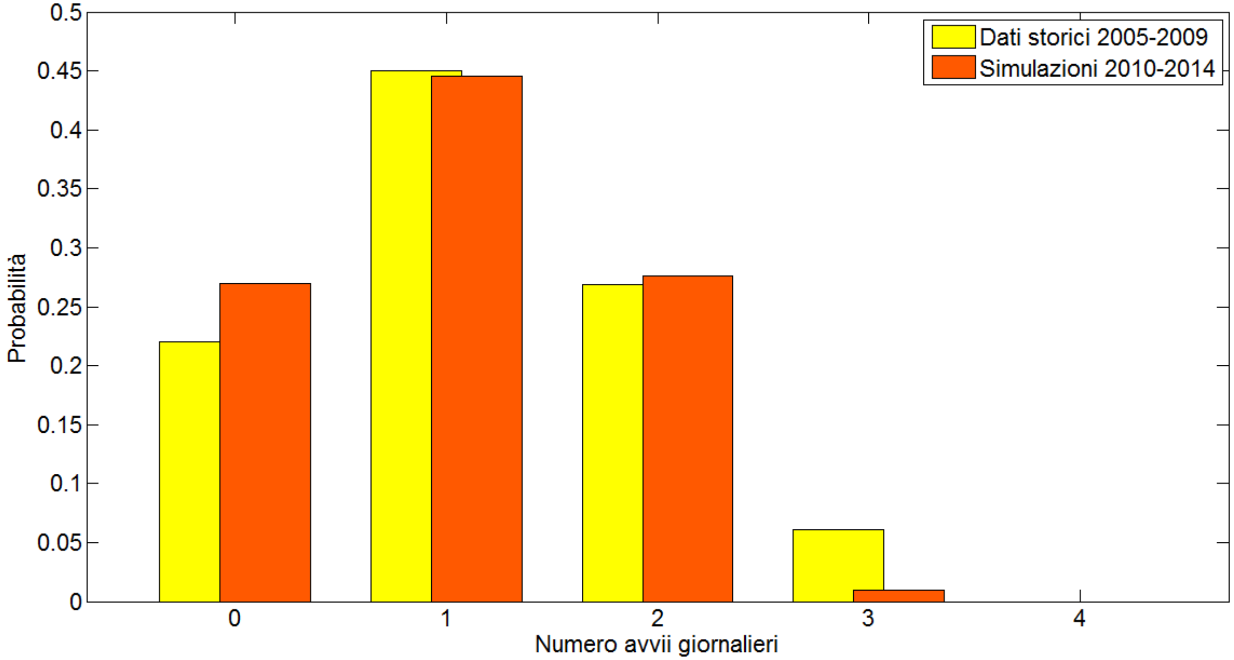
- By considering the **real** market quotations of EE in the 2005-2009 period, we would obtain:



- The hole in year 2008 corresponds to the high CO quotations.
- We can also observe that according to the period of the year the EPS should be switched on a different number of times in the day.

About switching on and off the EPS

- The distribution of the times when switching on the EPS during a single day is the following:



- It is worth observing how the EPS should be switched on (and consequently off) a maximum of 3 times per day. In addition there is a good agreement between the historical data (yellow bars) and the five-year simulations (orange bars).

About switching on and off the EPS

- **Further constraints** can be introduced in the economic assessment of the retrofitted HDA plant so to reduce to a **maximum of 1 or 2 operations per day** the EPS.
- A **further constraint** can also be the definition of the **minimum time** both EPS and FEHE sections should be operated (once again to reduce the mechanical and thermal stresses on the equipment).

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