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A two-stage approach to represent the daily LNG carriers unloading in natural gas optimization models

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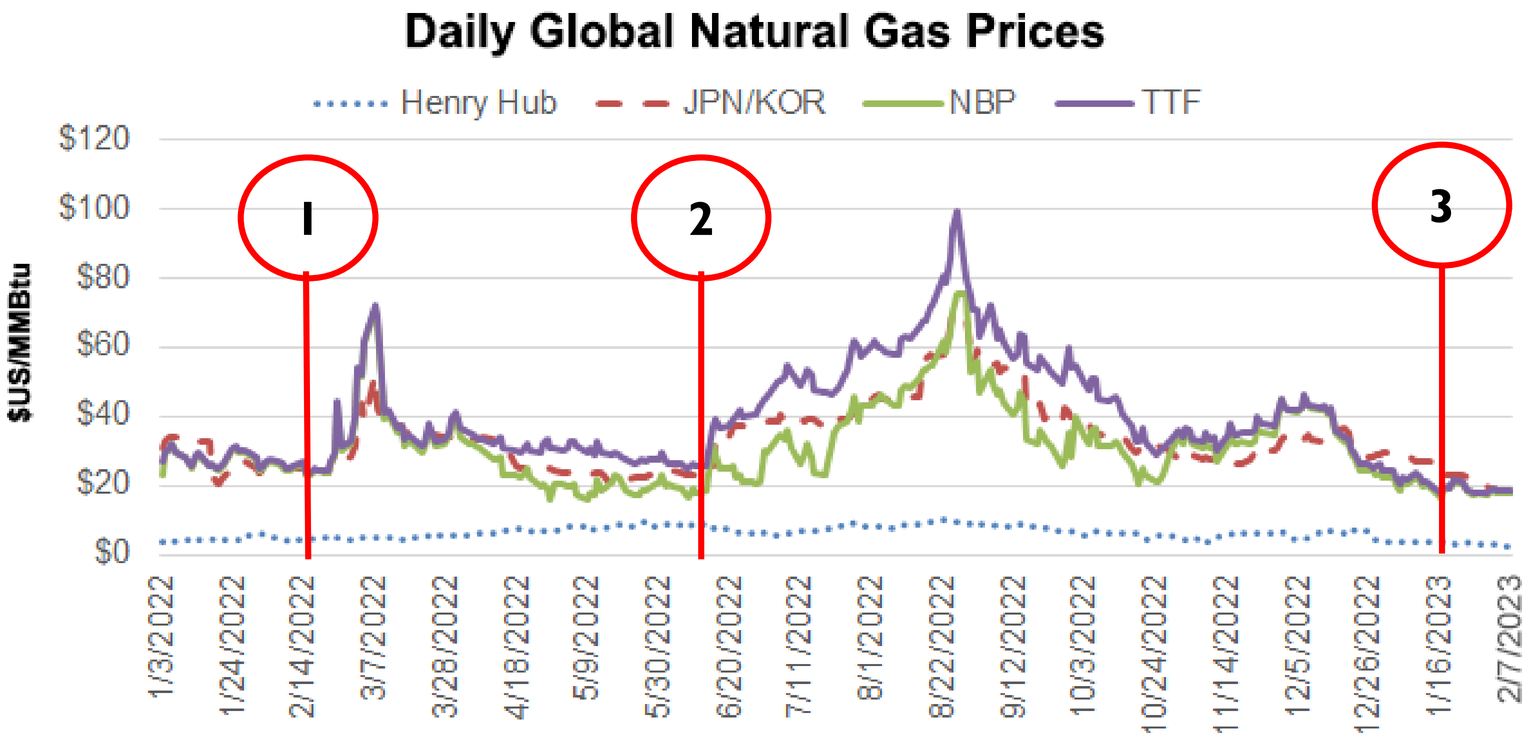
Background

- Natural gas is a crucial energy source for the next decade.
- Dependence on natural gas imports has increased, making supply vulnerable to disruptions and price fluctuations.
- Natural gas prices are highly unstable, especially compared to other commodities.

Background



Source: NGI's Daily Gas Price Index, NGI calculations, Bloomberg

1. **Ukraine invasión**
2. **Winter gas supply uncertainty**

3. Warm winter

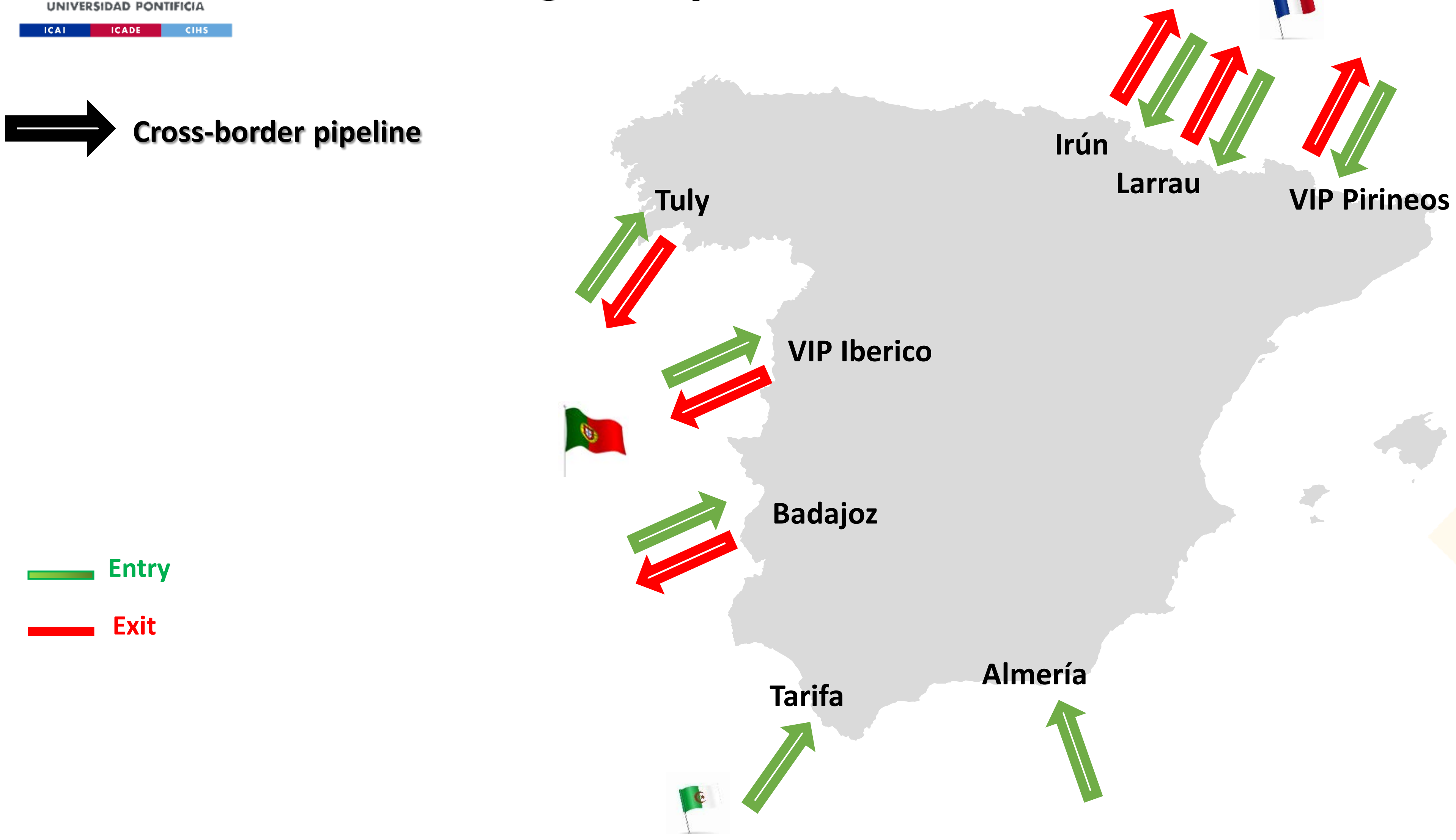
Gas demand decrease (industrial, electricity)

High storage filling level

Background

- Optimization models for natural gas systems are vital for policymakers and companies.
- These models enable impact assessment, forecasting, and what-if analysis.
- Modeling natural gas systems is challenging due to specialized infrastructure and the need for daily and long-term representation.

Natural gas optimization model



Source: enagas spanish gas system report 2022

Natural gas optimization model

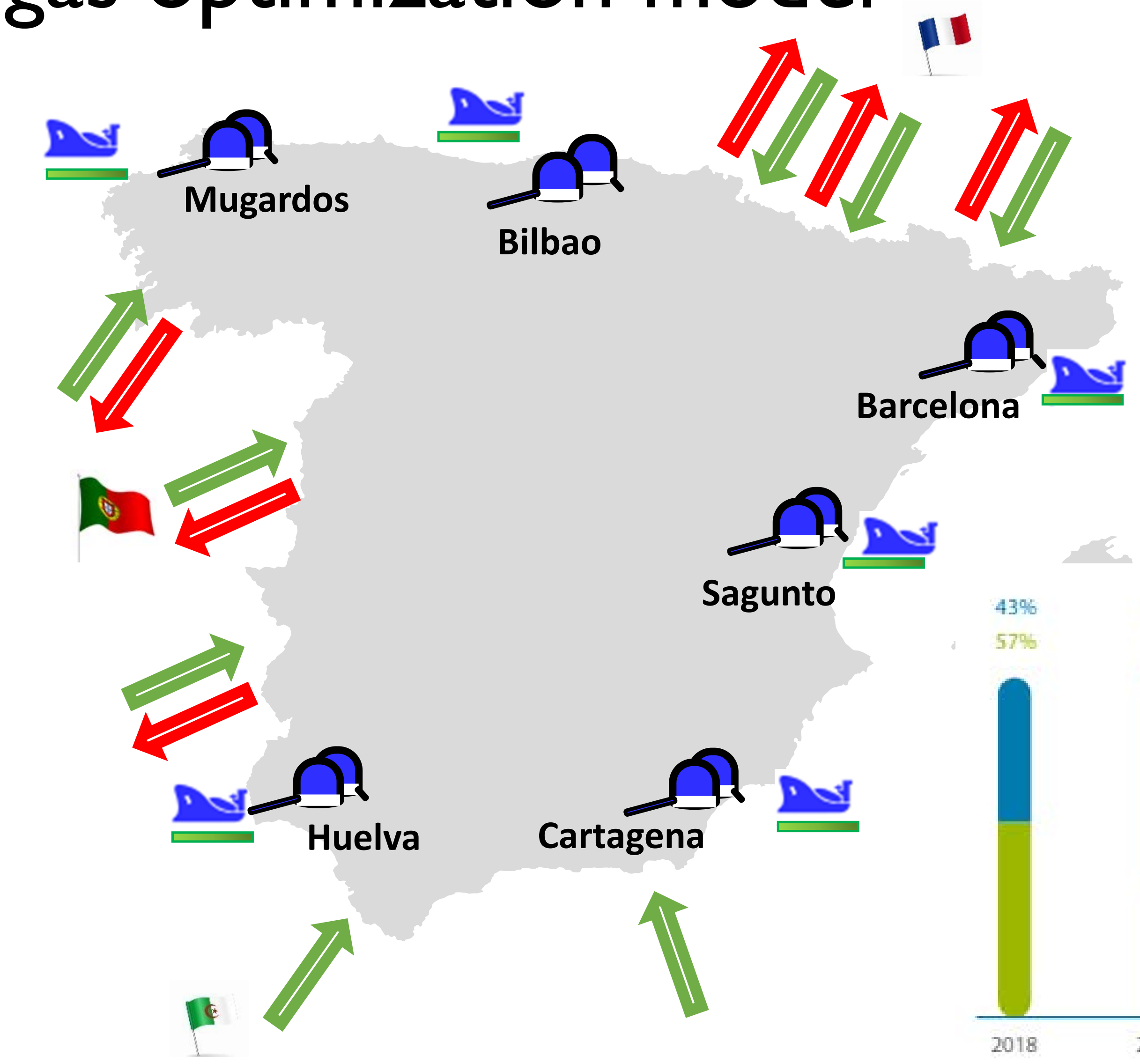
Cross-border pipeline

LNG vessel

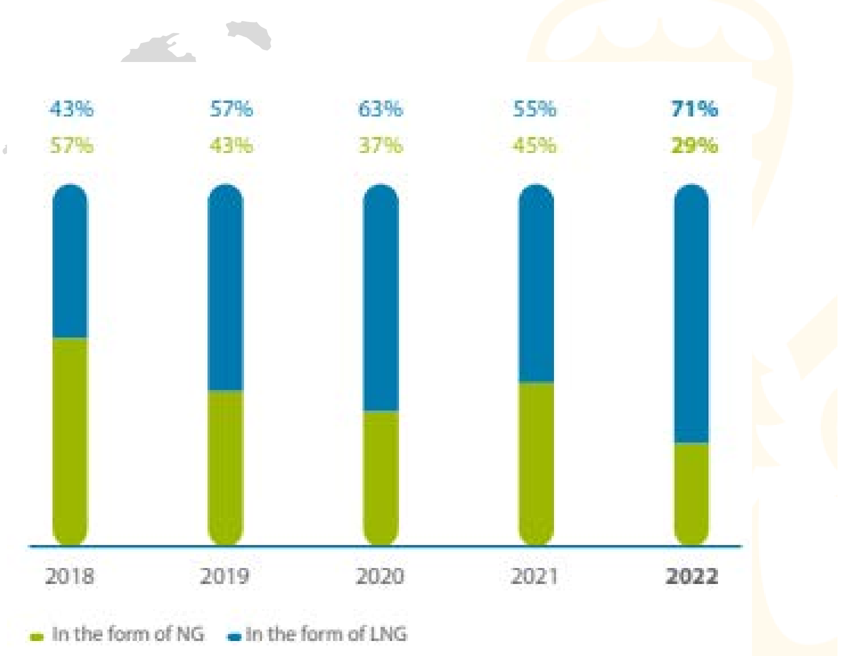
Regasification terminals

Entry

Exit



Supplies Evolution



Source: enagas spanish gas system report 2022

Natural gas optimization model

Cross-border pipeline

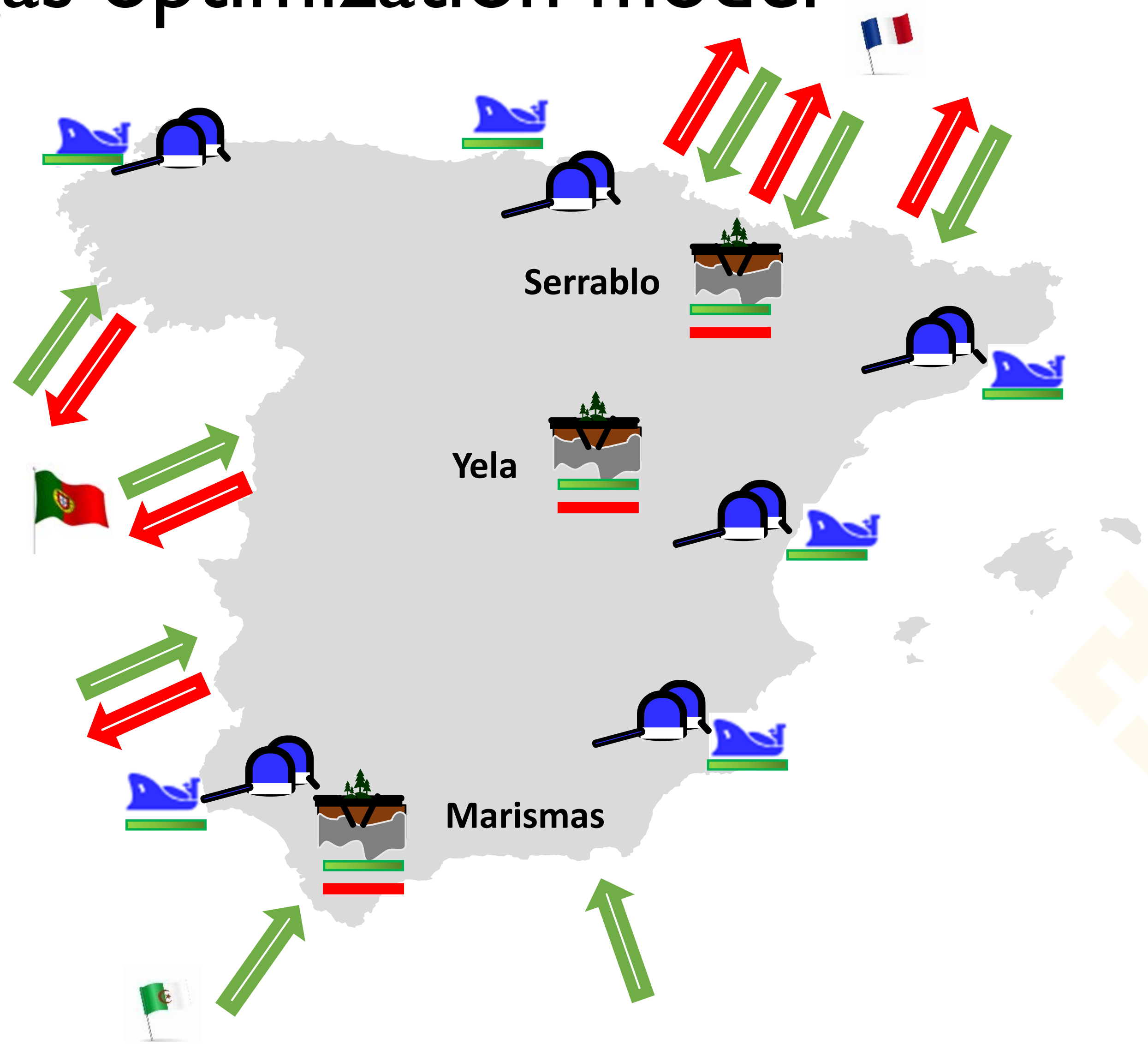
LNG vessel

Regasification terminals

Storage facility

Entry

Exit



Natural gas optimization model

Cross-border pipeline

LNG vessel

Regasification terminals

Storage facility

National demand

Entry

Exit

Natural gas optimization model- Objective function

- Cross-border pipeline
- LNG vessel
- Regasification terminals
- Storage facility
- Demand
- Entry
- Exit

Minimizing Cost

$$\Sigma_{x,z,e,t}\left(T_{xz}^{imp} * q_{xzet}^{imp} + T_{xz}^{exp} * q_{xzet}^{exp}\right) +$$

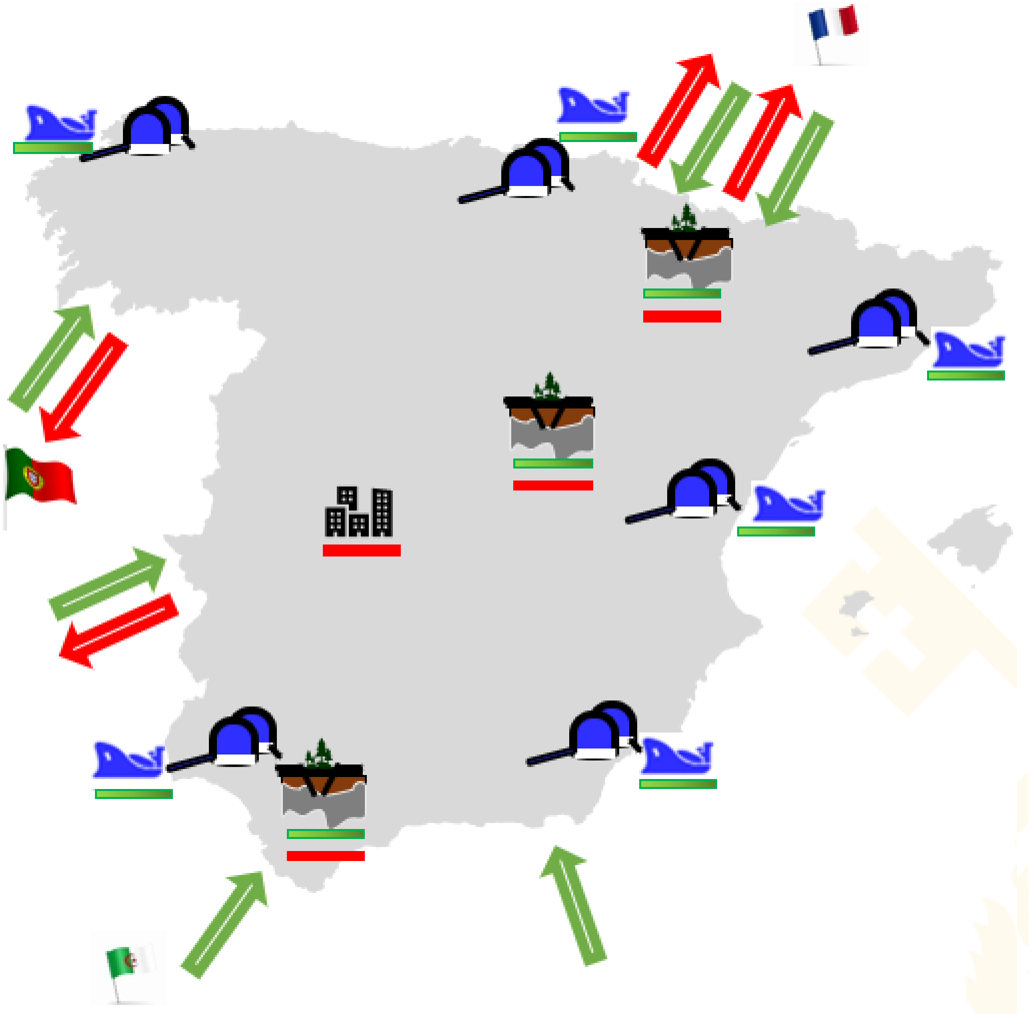
$$\sum_{i,r,w,e,t} T_{r}^{unload} * q_{irwet}^{unload} +$$

$$\sum_{r,e,t}\left(T_{r}^{reg} * q_{ret}^{reg} + T_{r}^{sto} * q_{ret}^{sto} + T_{r}^{LNG} * q_{ret}^{LNG}\right) +$$

$$\Sigma_{s,e,t}(T_{s}^{sto} * q_{set}^{sto} + T_{s}^{inj} * q_{set}^{inj} + T_{s}^{wth} * q_{set}^{wth})$$

Subject to:

- *Demand fulfillment*
- *Capacity constraints*
- *Supply contracts*



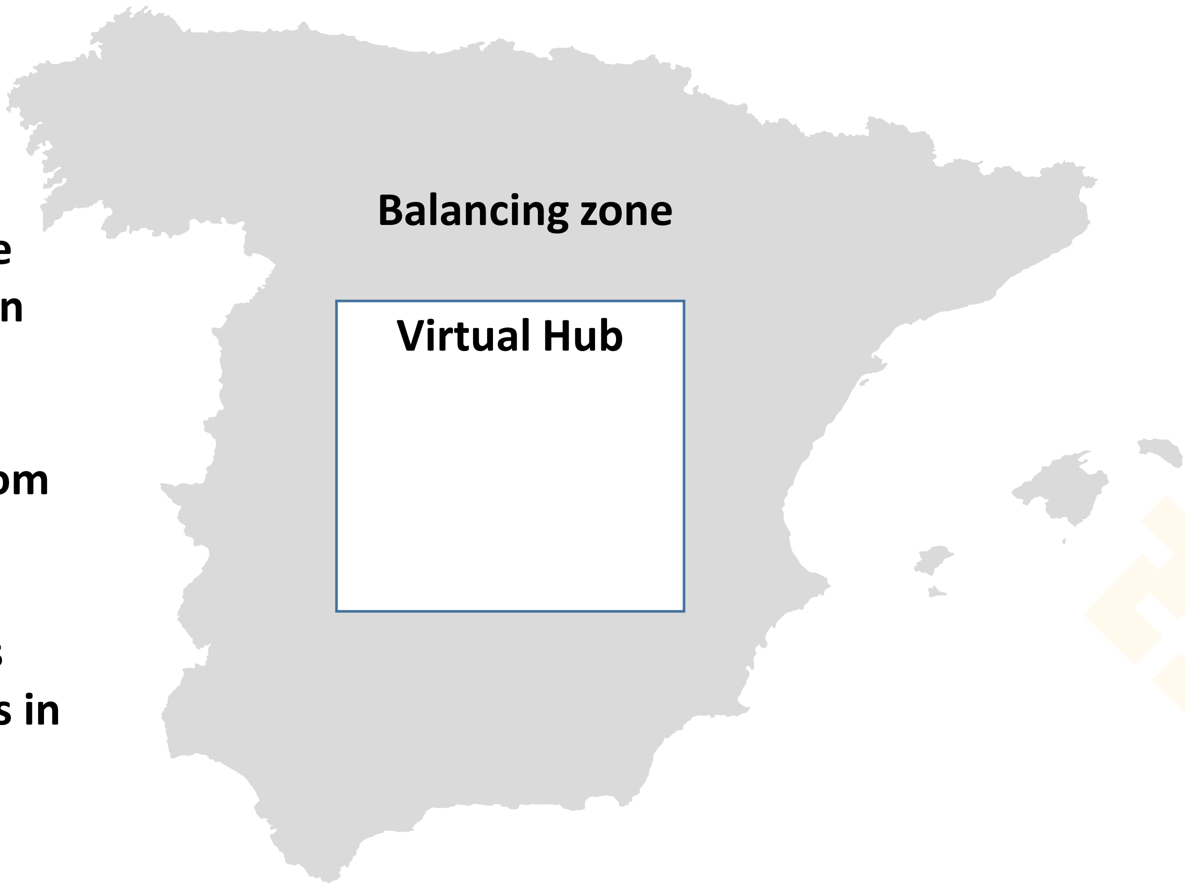
Indices:

e: *Agent* | *r*: *Regasification terminal* | *w*: *Berths of regasification terminals* | *z*: *Balancing zones*

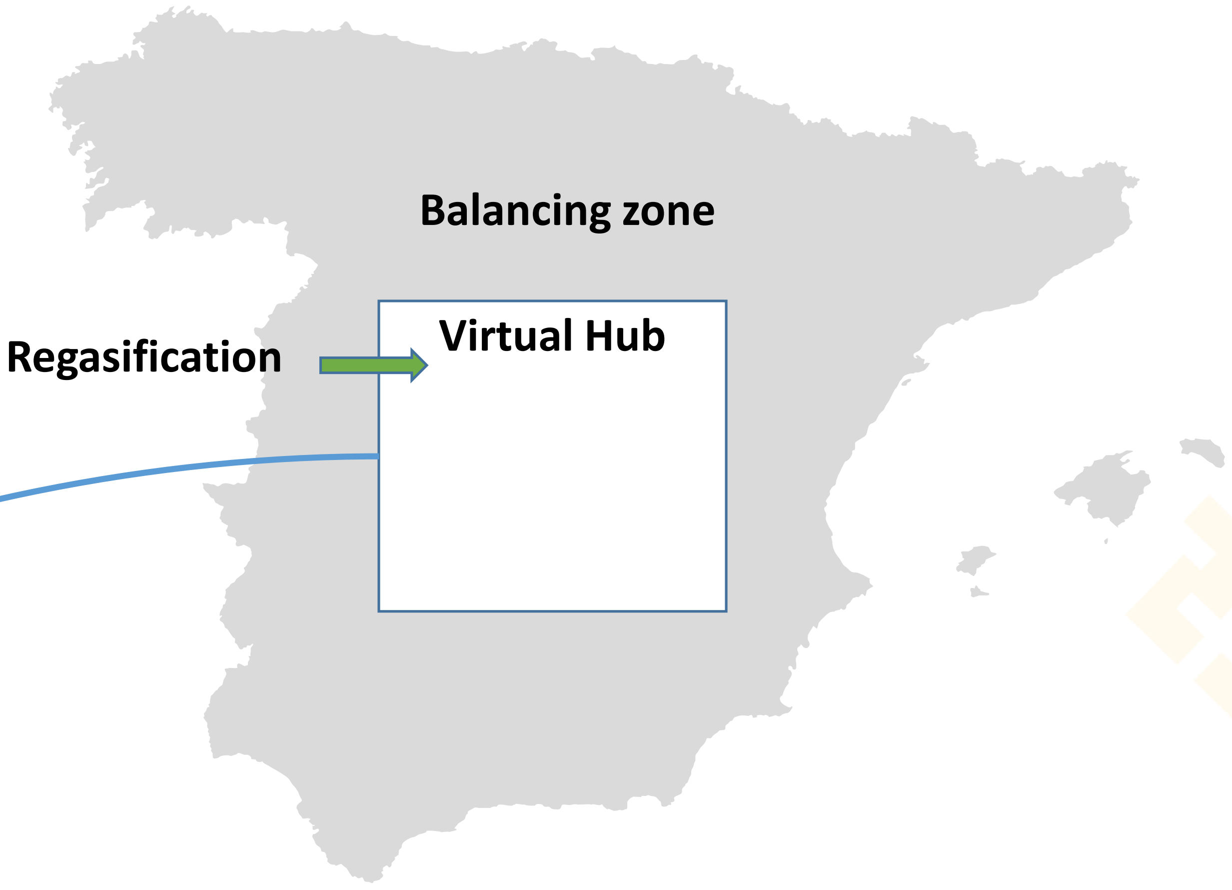
s: *Underground storages* | *x*: *Cross-border pipelines* | *t*: *Temporal (days or months depends on stage)* | *i*: *International markets*

Balancing zone and virtual hub

- **Simplifying representation of the Gas transmission and distribution network.**
- **Connect entry and exit points from a downstream gas market.**
- **Monitor daily shippers' balances and allow them to buy or sell gas in a virtual hub.**

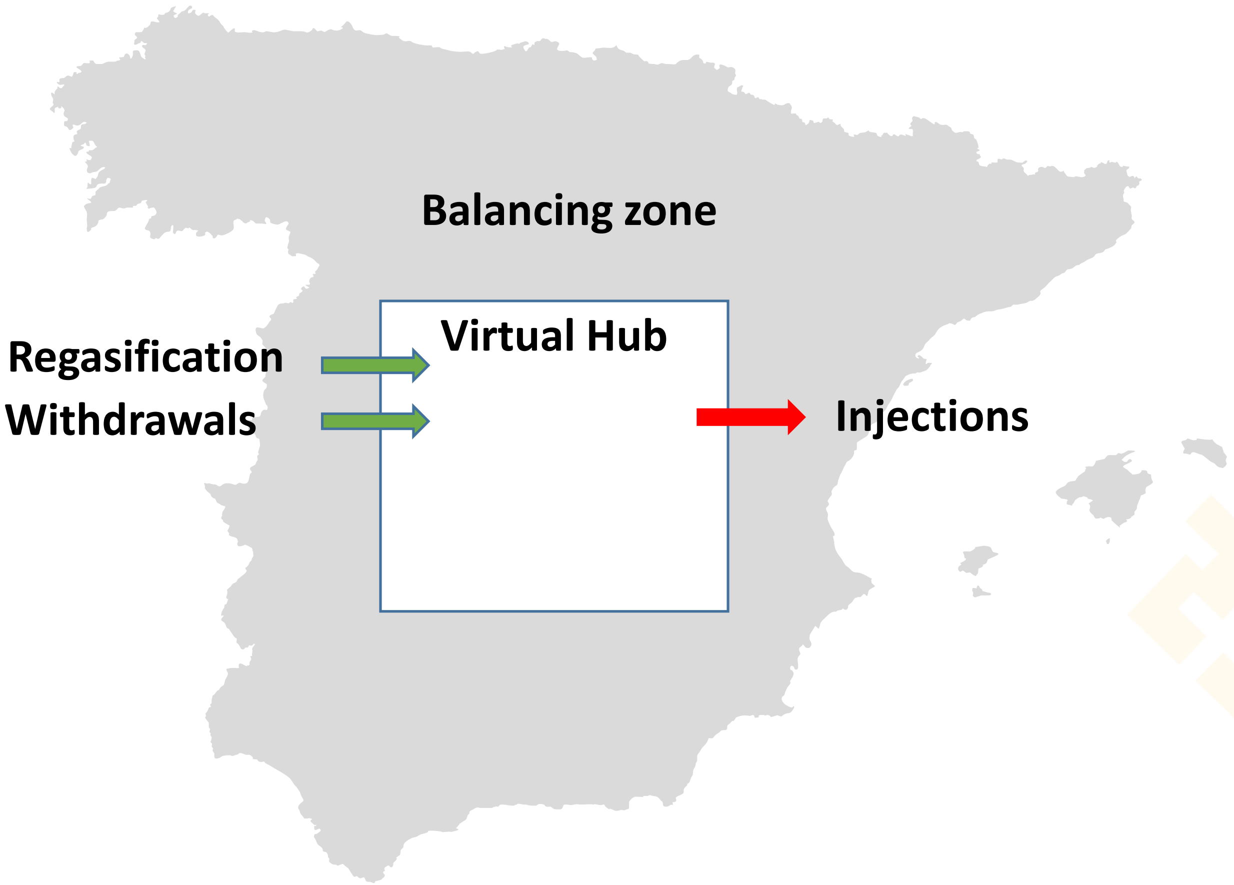


Balancing operations in a virtual hub



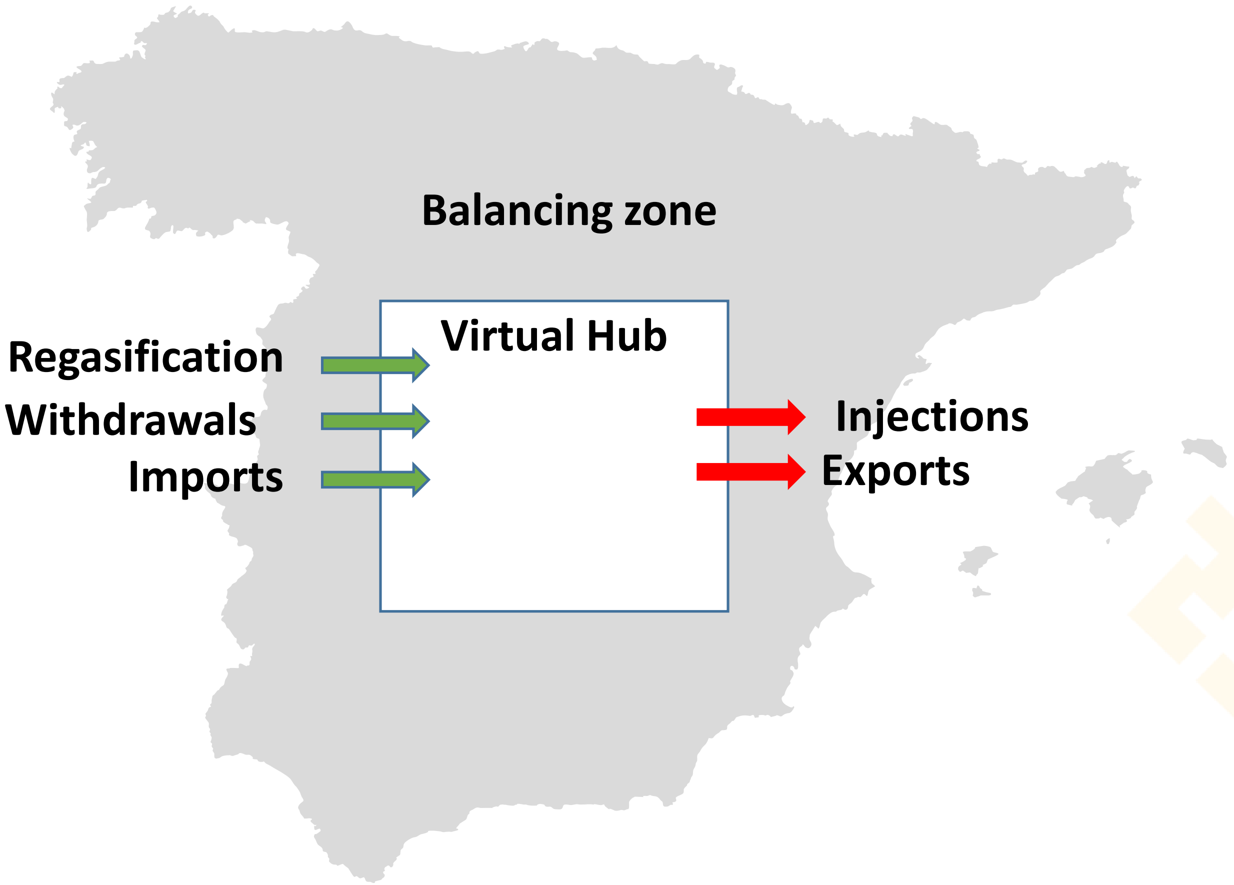
$$q_{zet}^{HUB} - q_{ze(t-1)}^{HUB} = \sum_{r \in z} q_{ret}^{reg} +$$

Balancing operations in a virtual hub



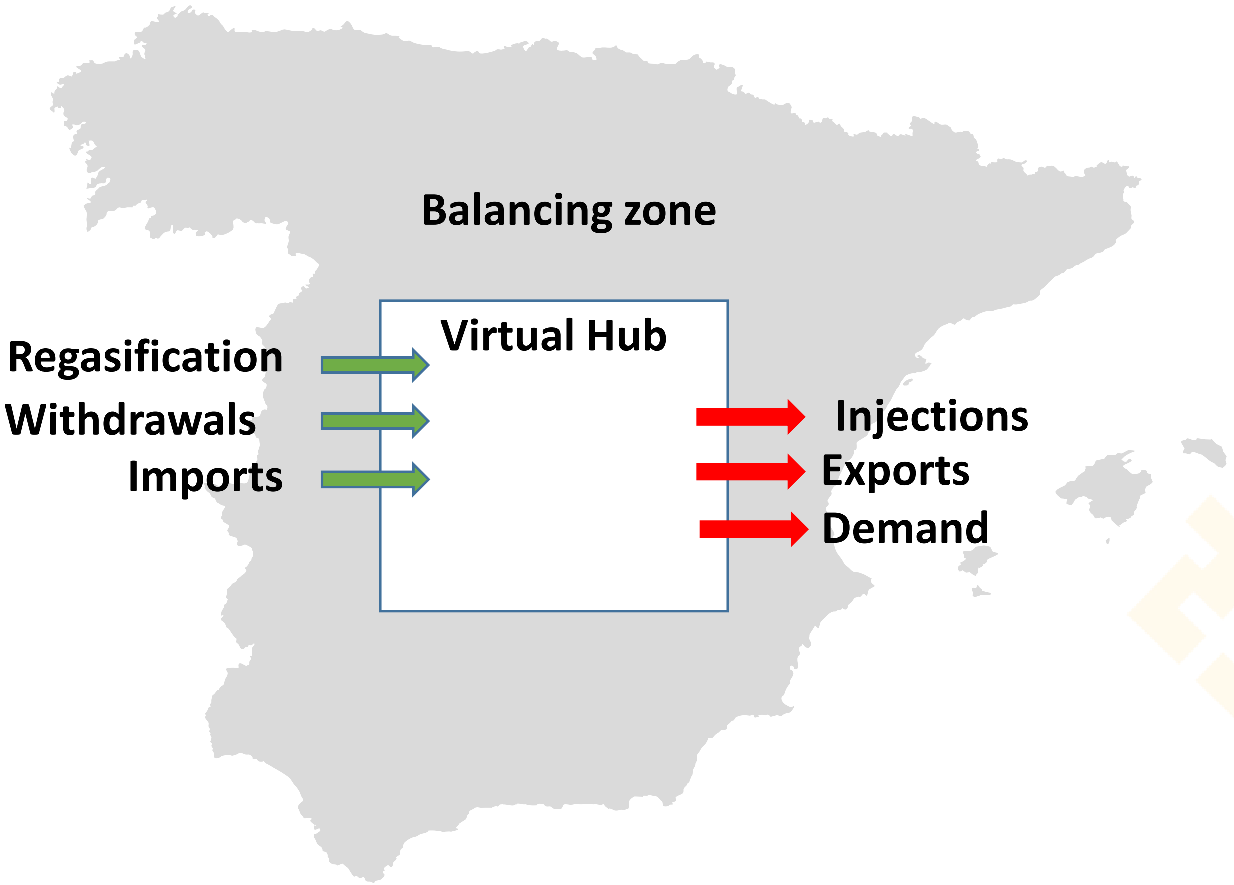
$$q_{zet}^{HUB} - q_{ze(t-1)}^{HUB} = \sum_{r \in z} q_{ret}^{reg} + \sum_{s \in z} \left(q_{set}^{wth} - q_{set}^{inj}\right) +$$

Balancing operations in a virtual hub



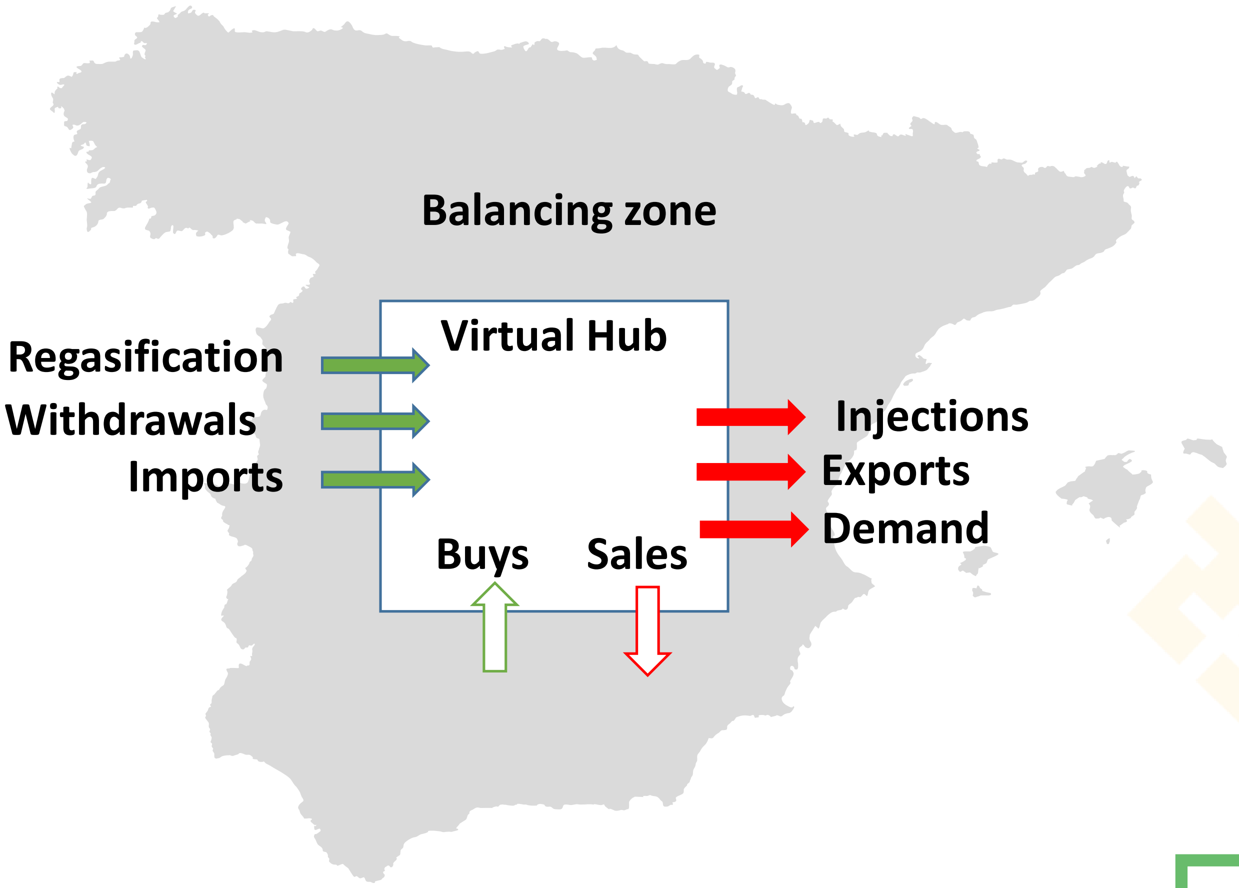
$$q_{zet}^{HUB} - q_{ze(t-1)}^{HUB} = \sum_{r\in z} q_{ret}^{reg} + \sum_{s\in z}\left(q_{set}^{wth} - q_{set}^{inj}\right) + \sum_{x}\left(q_{xzet}^{imp} - q_{xzet}^{exp}\right)$$

Balancing operations in a virtual hub



$$q_{zet}^{HUB} - q_{ze(t-1)}^{HUB} = \sum_{r \in z} q_{ret}^{reg} + \sum_{s \in z} \left(q_{set}^{wth} - q_{set}^{inj} \right) + \sum_{x} \left(q_{xzet}^{imp} - q_{xzet}^{exp} \right) - D_{zet}^{TOT}$$

Balancing operations in a virtual hub

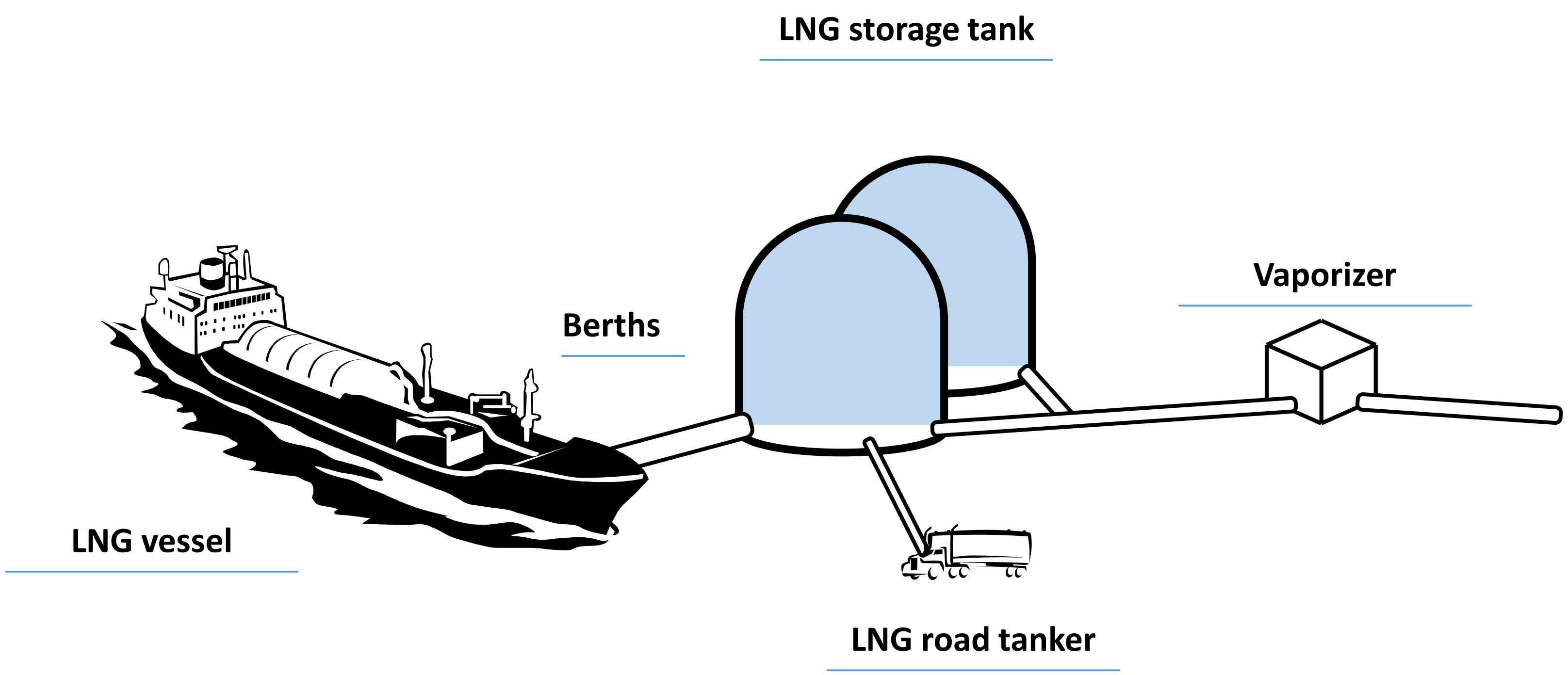


$$q_{zet}^{HUB} - q_{ze(t-1)}^{HUB} = \sum_{r \in z} q_{ret}^{reg} + \sum_{s \in z} (q_{set}^{wth} - q_{set}^{inj}) + \sum_{x} (q_{xzet}^{imp} - q_{xzet}^{exp}) - D_{zet}^{TOT} + q_{zet}^{\Delta HUB} - q_{zet}^{\nabla HUB}$$

HUB Price – Dual variable

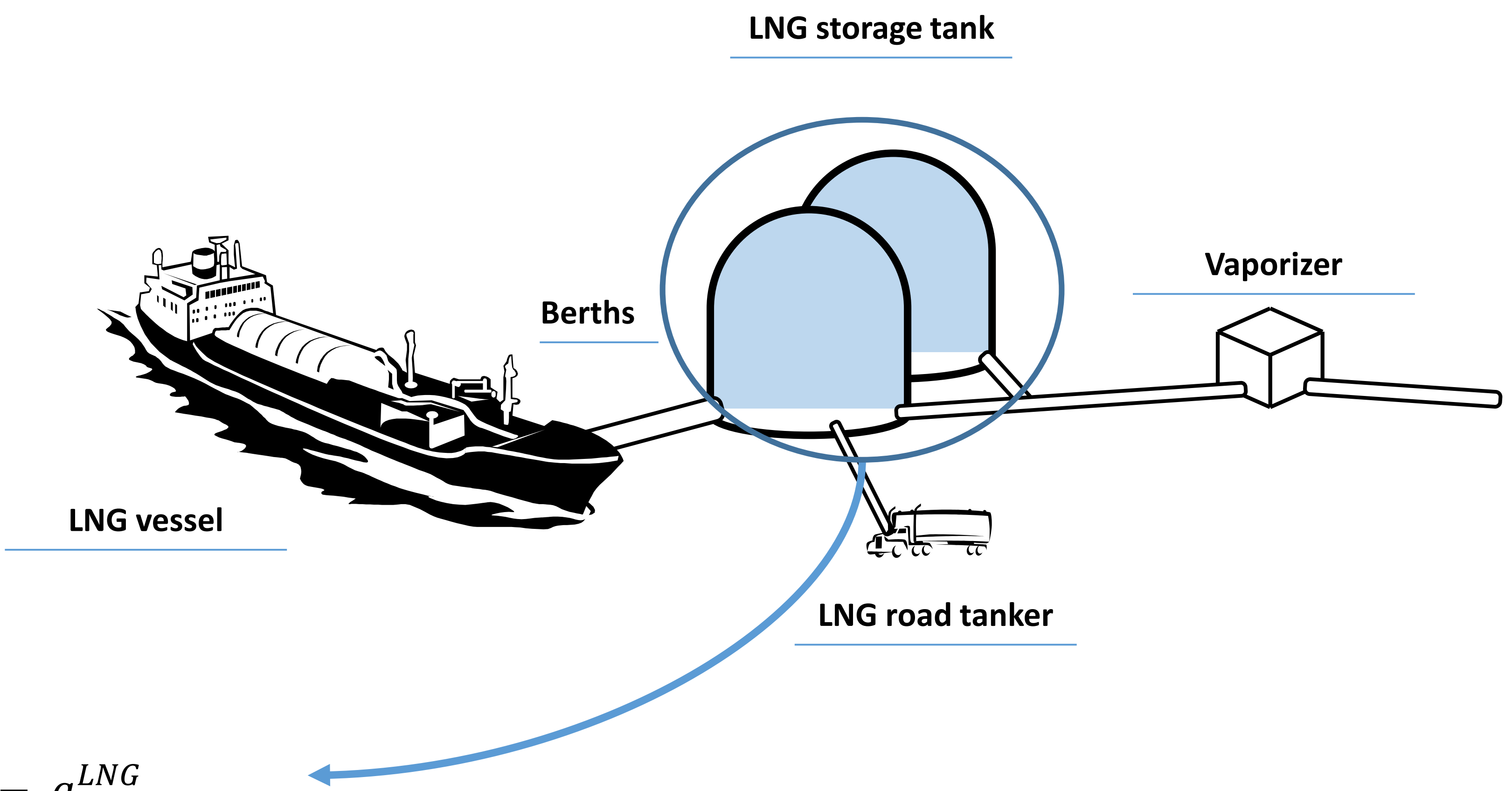
$$\sum_{e} q_{zet}^{\Delta HUB} - q_{zet}^{\nabla HUB} = 0$$

Balancing operations - regasification terminals



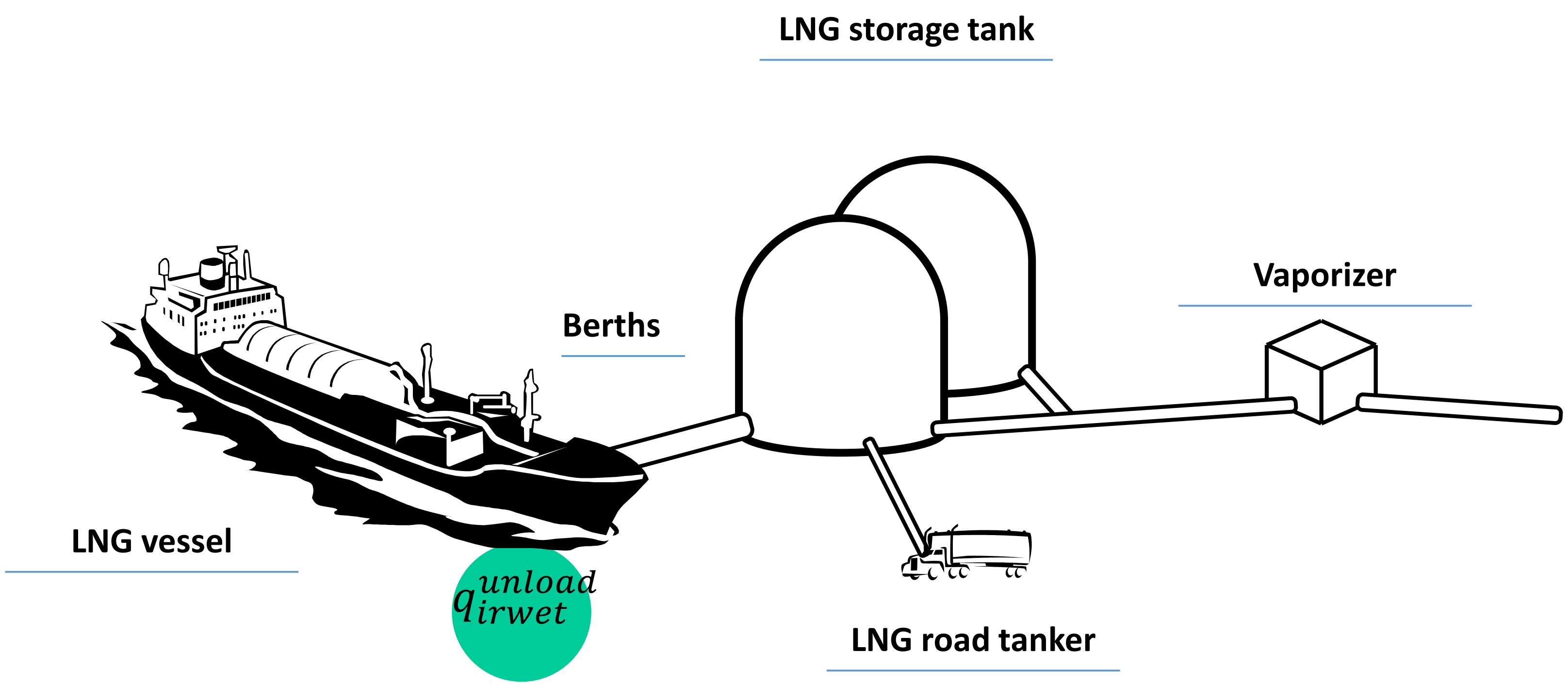
$$q_{ret}^{LNG} - q_{re(t-1)}^{LNG}$$

Balancing operations - regasification terminals



$$q_{ret}^{LNG} - q_{re(t-1)}^{LNG}$$

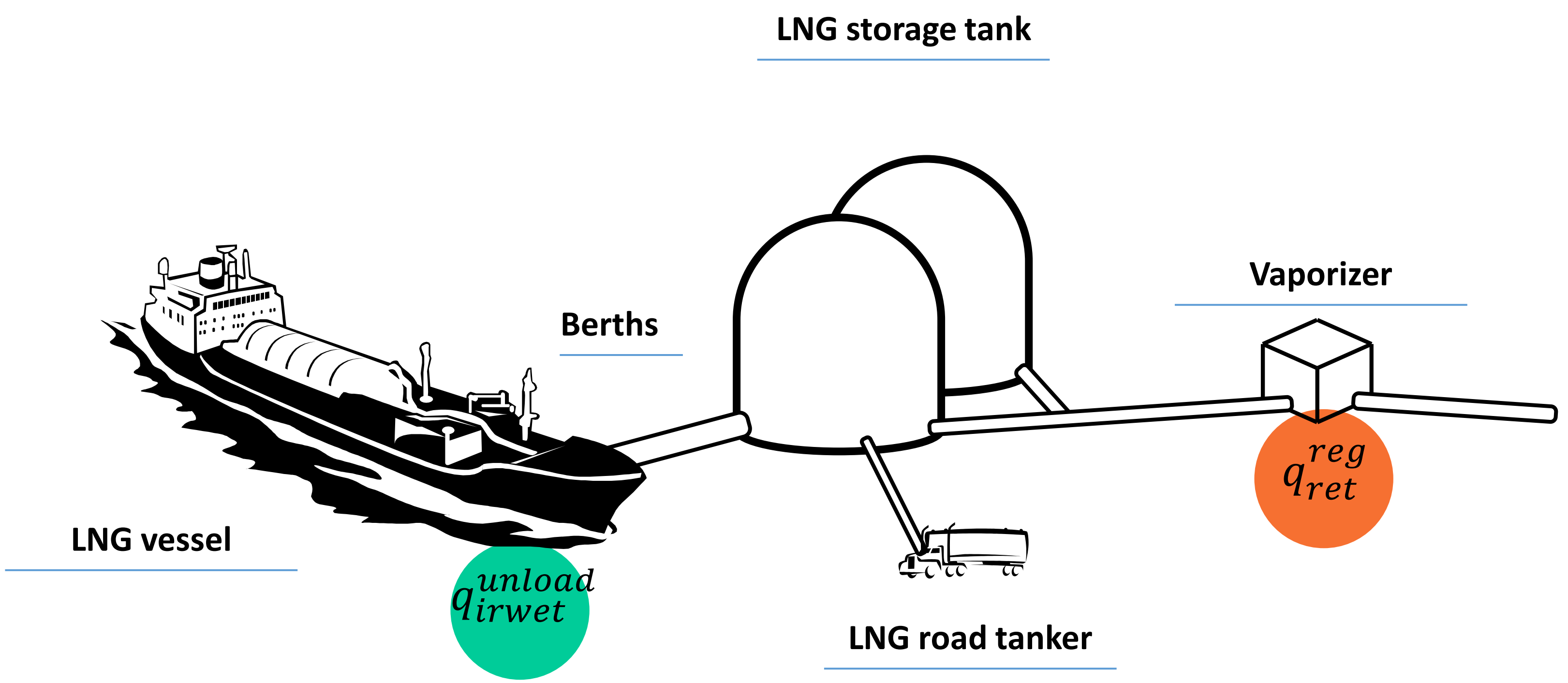
Balancing operations - regasification terminals



By: Agent

$$q_{ret}^{LNG} - q_{re(t-1)}^{LNG} = \sum_{i,w} q_{irwet}^{unload} - \dots$$

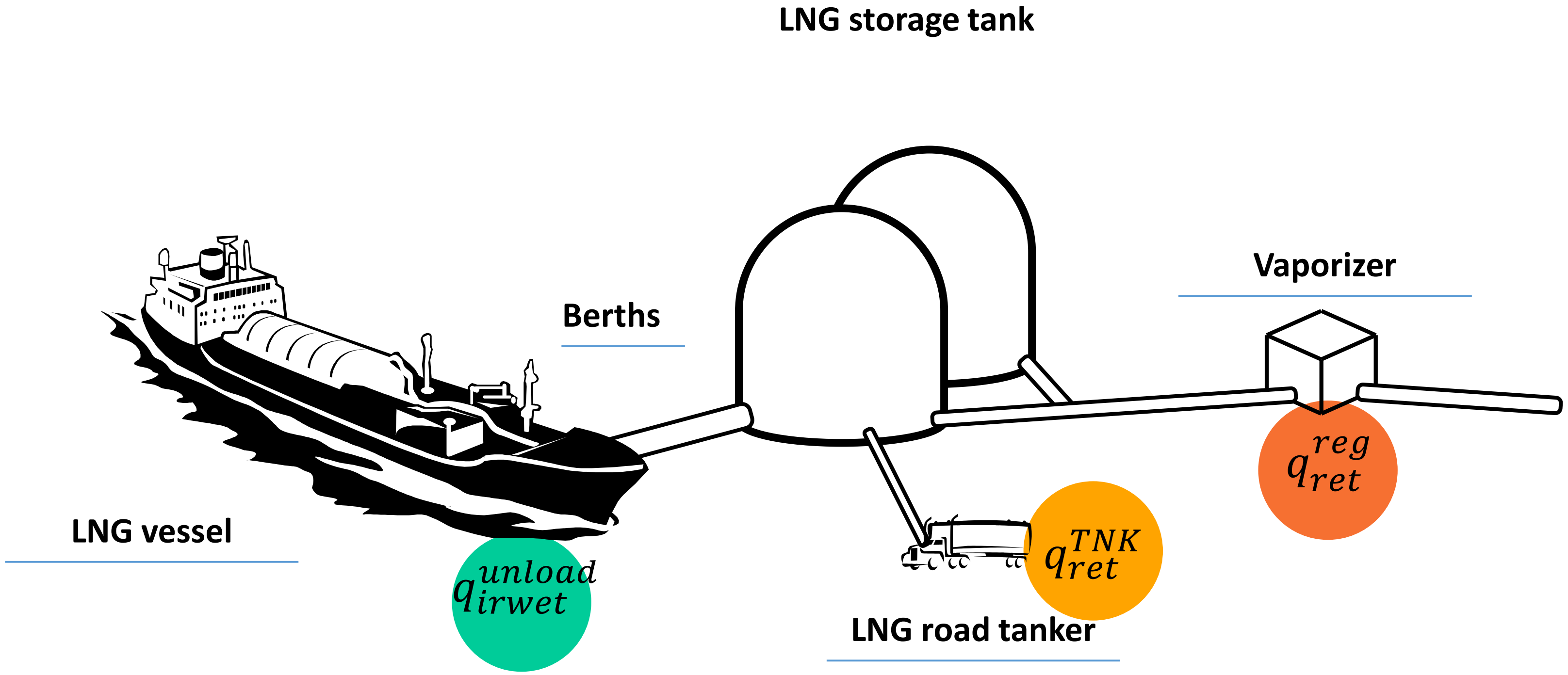
Natural gas optimization model



By: Agent

$$q_{ret}^{LNG} - q_{re(t-1)}^{LNG} = \sum_{i,w} q_{irwet}^{unload} - q_{ret}^{reg} + \dots$$

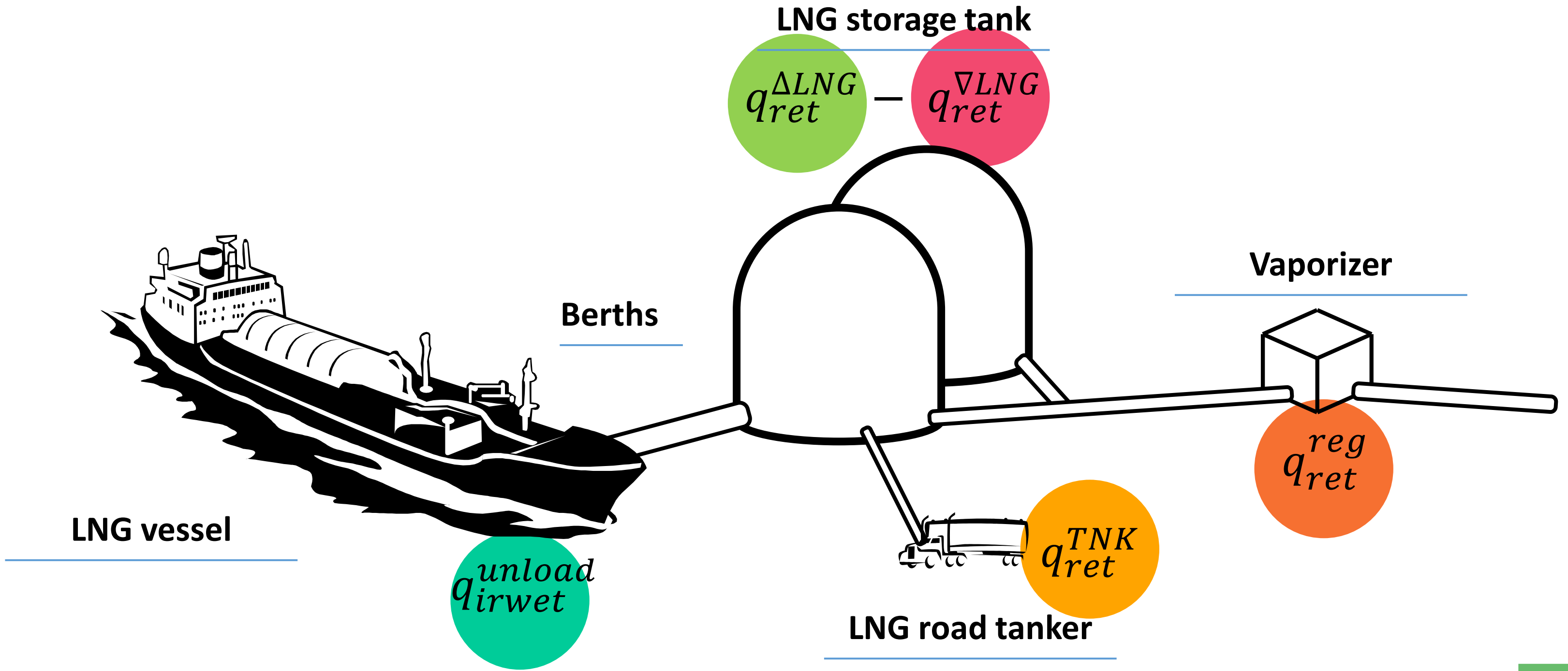
Balancing operations - regasification terminals



By: Agent

$$q_{ret}^{LNG} - q_{re(t-1)}^{LNG} = \sum_{i,w} q_{irwet}^{unload} - q_{ret}^{reg} - q_{ret}^{TNK} + \dots$$

Balancing operations - regasification terminals



By: Agent

$$q^{LNG}_{ret} - q^{LNG}_{re(t-1)} = \sum_{i,w} q^{unload}_{irwet} - q^{reg}_{ret} - q^{TNK}_{ret} + q^{\Delta LNG}_{ret} - q^{\nabla LNG}_{ret}$$

LNG storage tank Price – Dual Variable

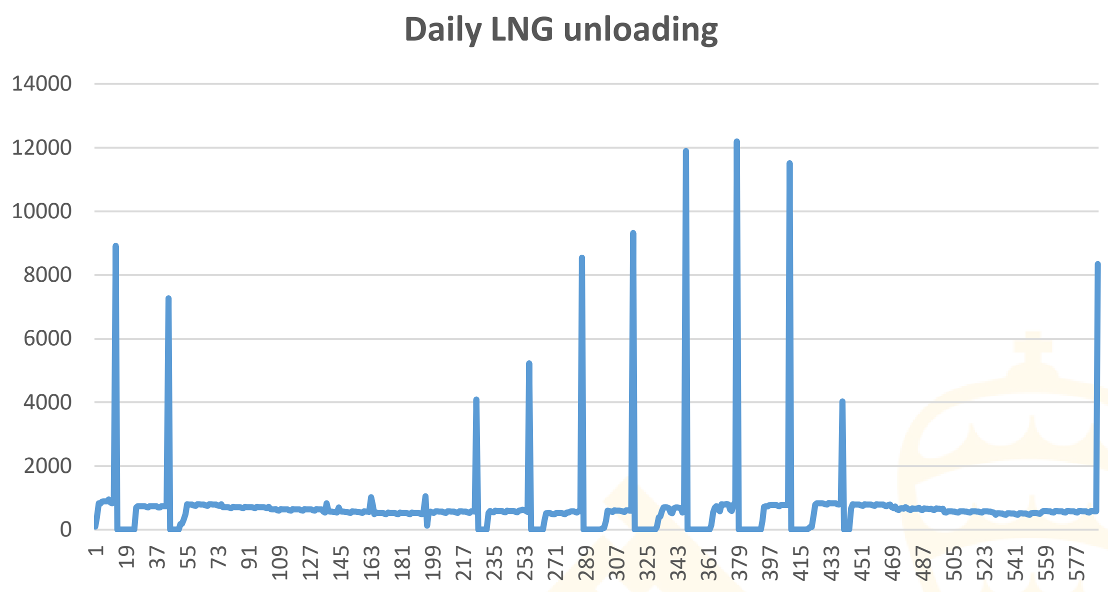
$$\sum_{e} q^{\Delta LNG}_{ret} - q^{\nabla LNG}_{ret} = 0$$

Business problem

- Daily level + multiple years
- Detailed representation
- Significant computational burden associated with such detail in large-scale gas systems.

Business problem

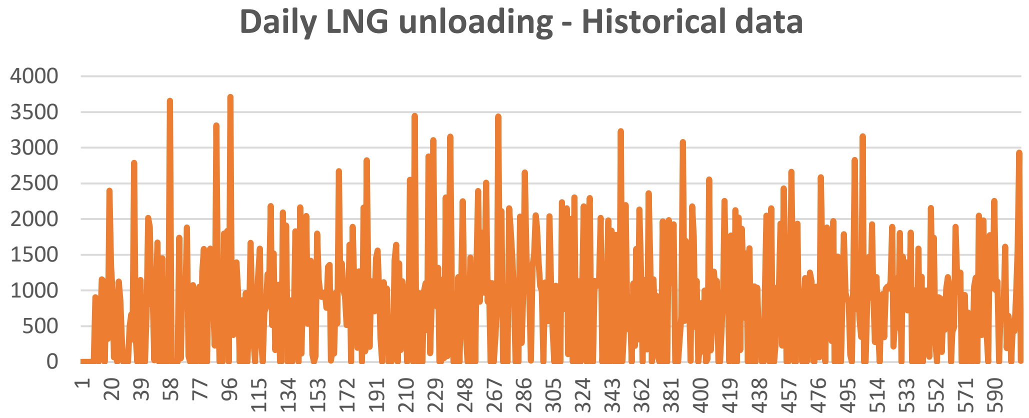
- Under deterministic optimization, perfect foresight leads agents to anticipate all future shocks perfectly, resulting in unrealistic decisions.
- This is particularly the case with the LNG carrier unloading schedules. Where daily patterns present spikes on specific days of the month.



Two-stage approach

Historical data.

Daily unloading volumes of LNG.



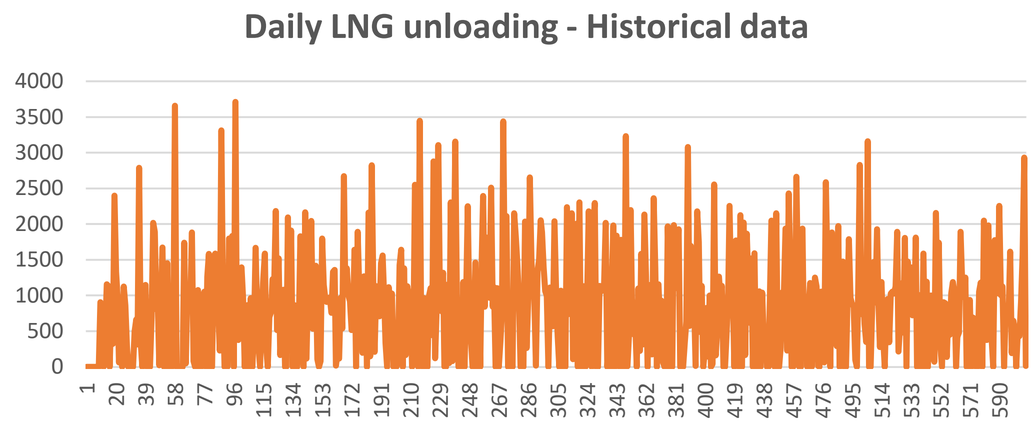
Twelve years of historical data.

Two-stage approach

Historical data.

Daily unloading volumes of LNG.

The probability of vessel arrivals at the regasification plant per day is calculated for each month.



Twelve years of historical data.

January 31 days * 12 years = 372 total data

January probability of vessel = # days with unloadings/372
Arrivals per day

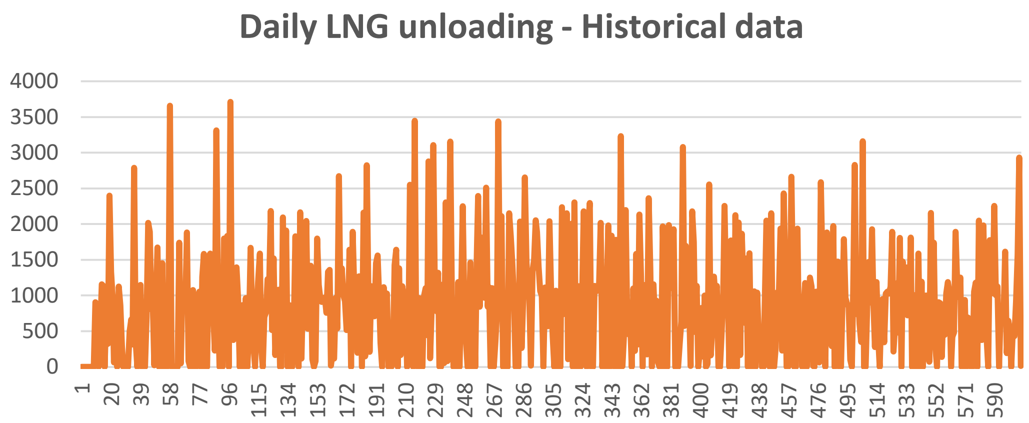
Two-stage approach

Historical data.

Daily unloading volumes of LNG.

The probability of vessel arrivals at the regasification plant per day is calculated for each month.

The binomial distribution is used to define daily vessel arrivals.



Twelve years of historical data.

Two-stage approach

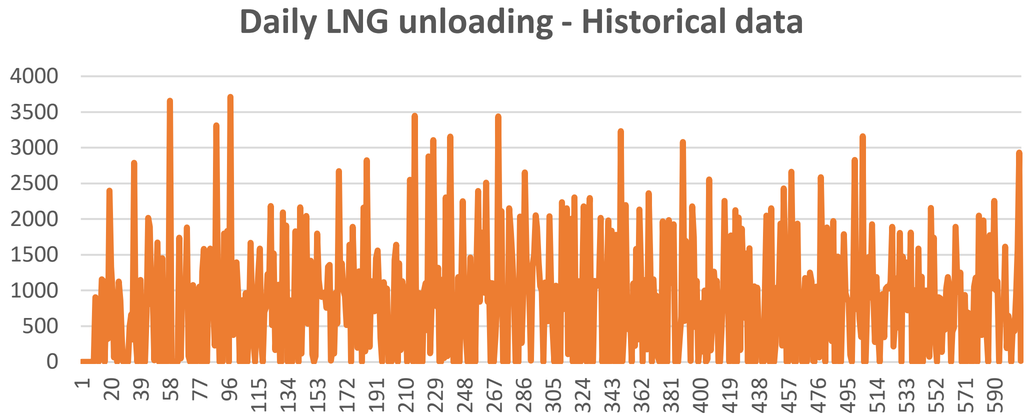
Historical data.

Daily unloading volumes of LNG.

The probability of vessel arrivals at the regasification plant per day is calculated for each month.

The binomial distribution is used to determine daily vessel arrivals.

the volume to be unloaded is sorted according to the maximum berthing capacity.



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Two-stage approach

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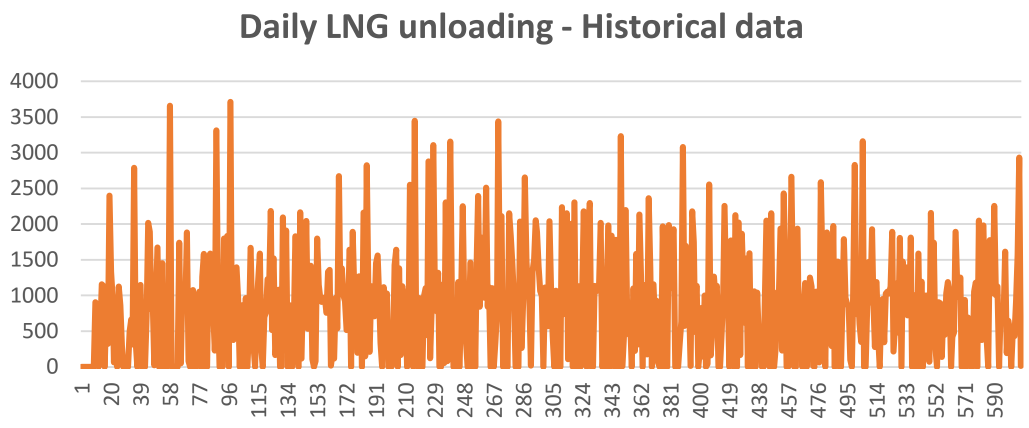
Daily unloading volumes of LNG.



Twelve years of historical data.

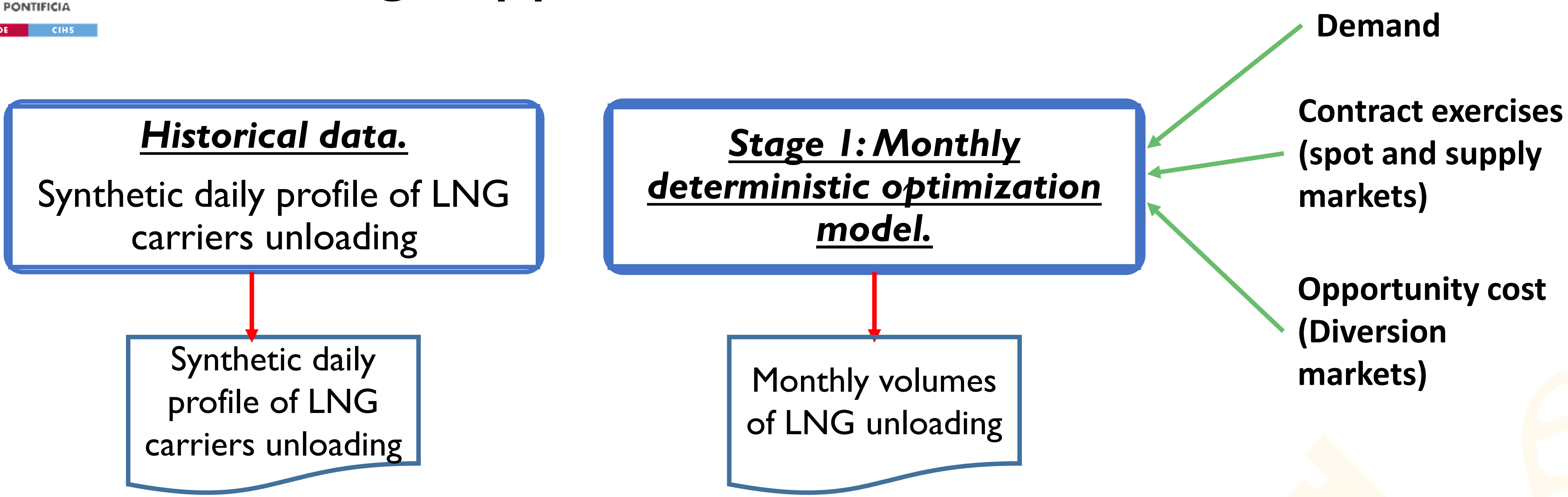
The probability of vessel arrivals at the regasification plant per day is calculated for each month.

The binomial distribution is used to determine daily vessel arrivals.

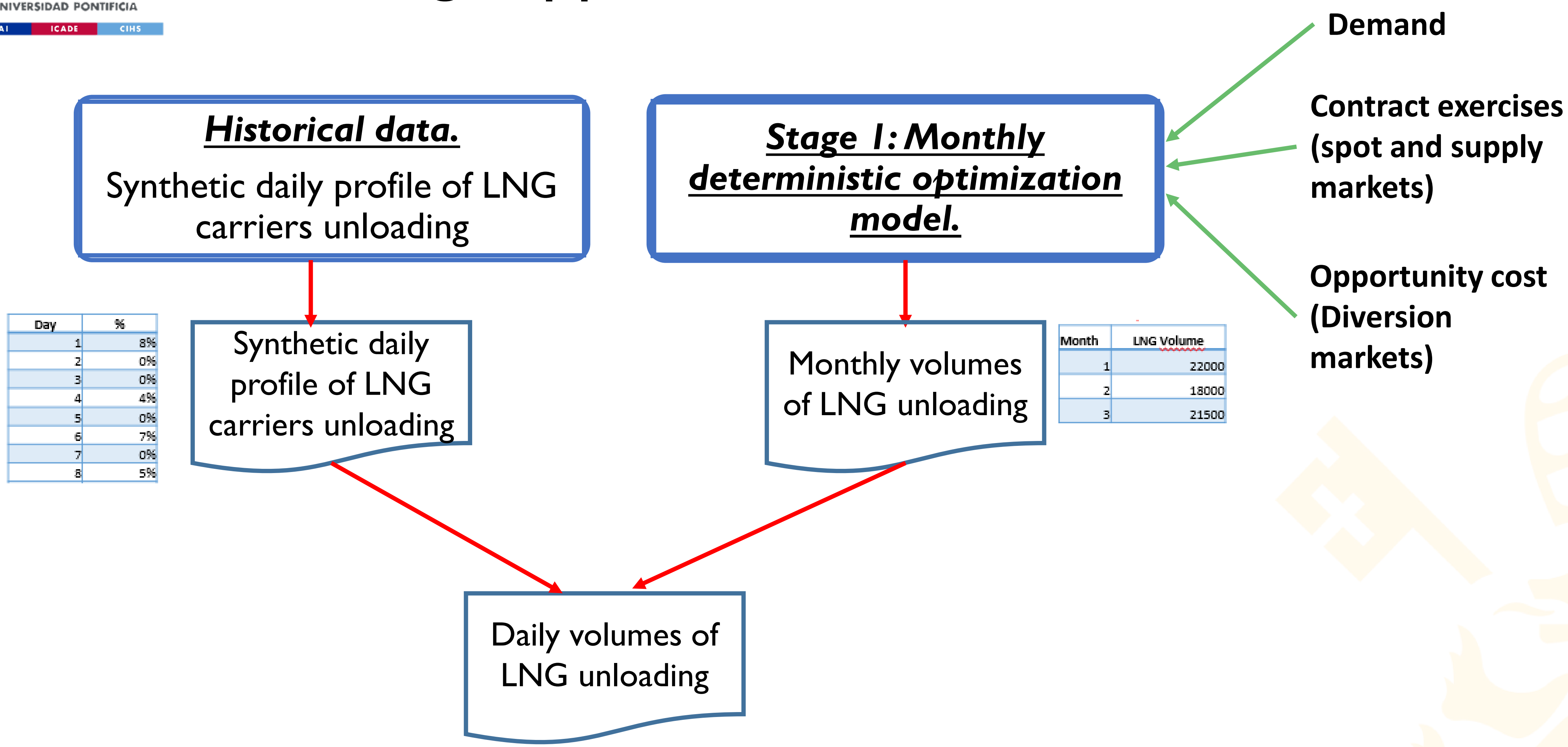
the volume to be unloaded is sorted according to the maximum berthing capacity.

Synthetic daily profile of LNG carriers unloading

Two-stage approach



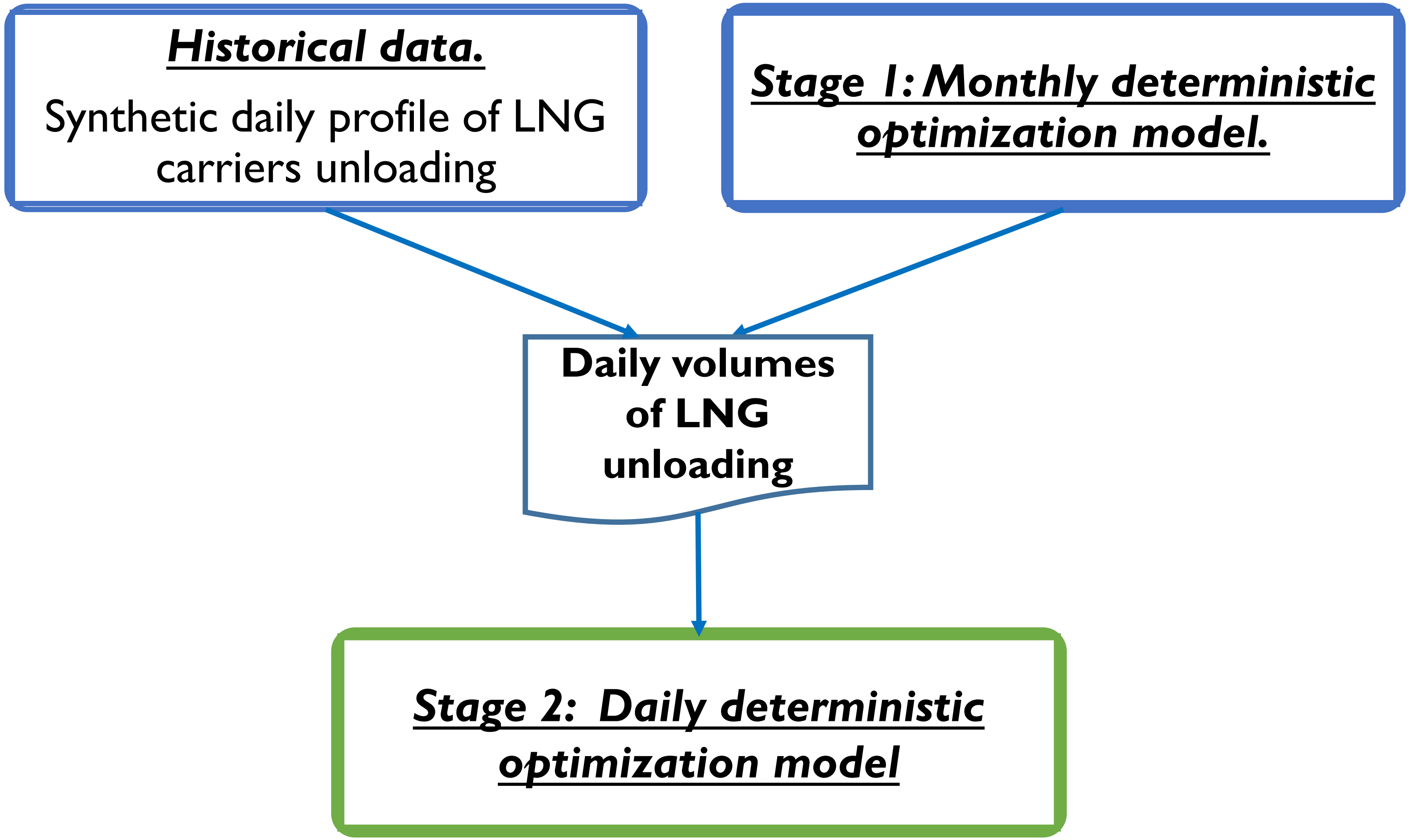
Two-stage approach



Day	%
1	8%
2	0%
3	0%
4	4%
5	0%
6	7%
7	0%
8	5%

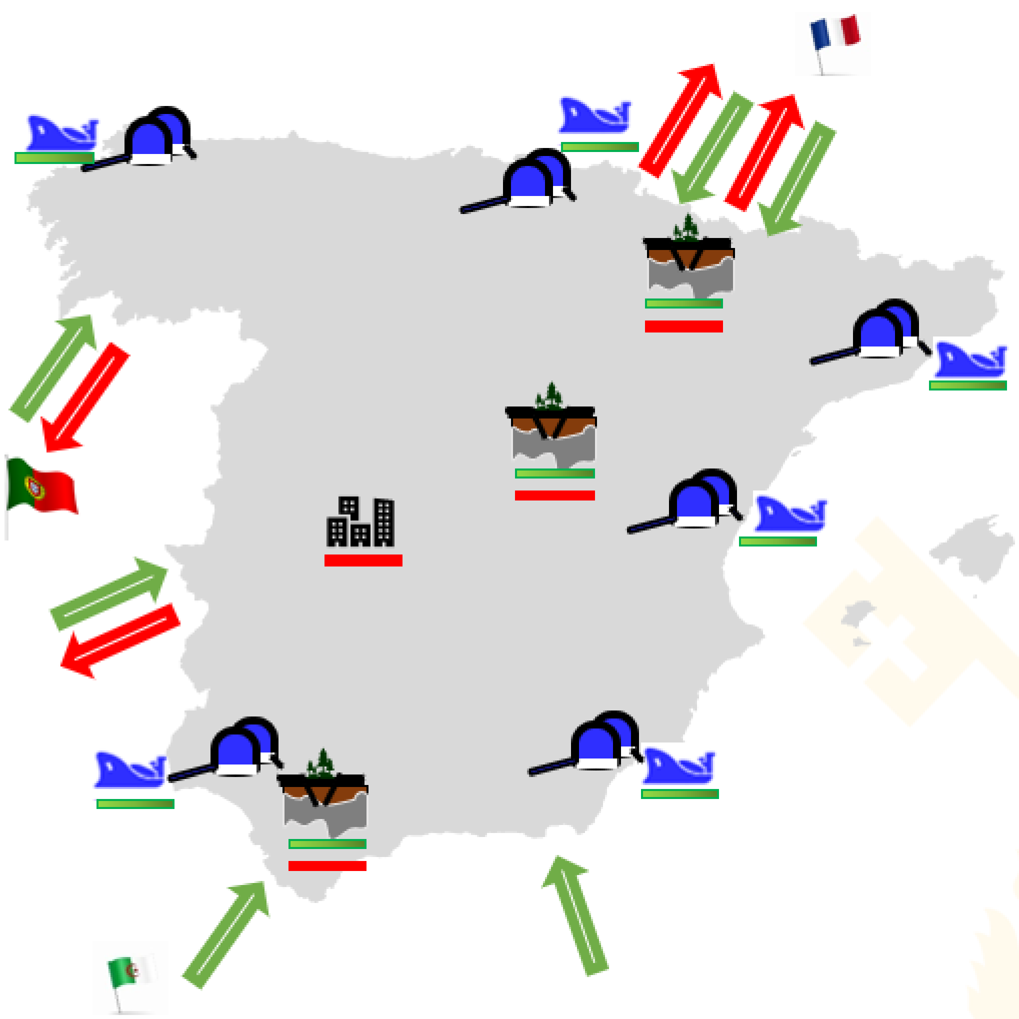
Month	LNG Volume
1	22000
2	18000
3	21500

Two-stage approach



Case study

- Real-size scale
- Detailed representation of the Iberian gas system (Spain and Portugal).
- Case 1: The model is allowed to determine the optimal value for daily LNG carrier unloading.
- Case 2: Adopt the two-step methodology



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Case study – key features

Cross-boarder pipelines

8

*11,369 km

Primary transmission pipelines (13,361 km, including secondary ones)

International markets

*19

Countries supplying to the System

LNG Vessels

*+33%

Unloadings of LNG vs. 2021

Regasification terminals

6

*+48%

Regasification terminal production vs. 2021

Storage Facility

4

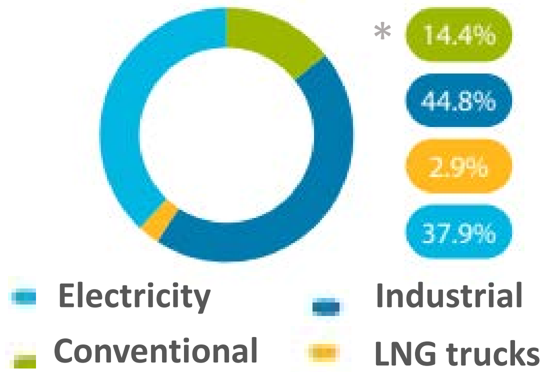
*94%

Filling level of storage facilities in Spain on 1 November (level required by EU regulations): 80%)

*Source: enagas spanish gas system report 2022

Case study – key features

National demand



*50

Participating shippers
in capacity auctions

681.916

Constraints

2.290.424

Variables

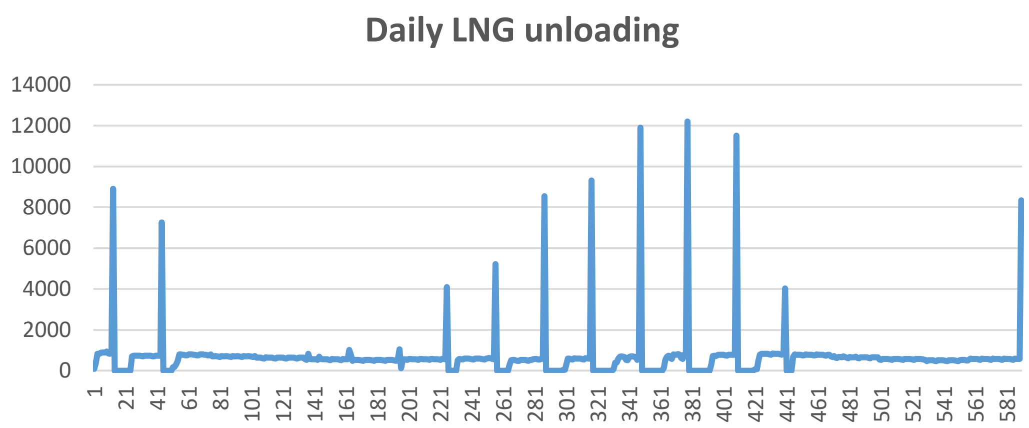
Mid-term horizon

two years ahead on a daily basis.

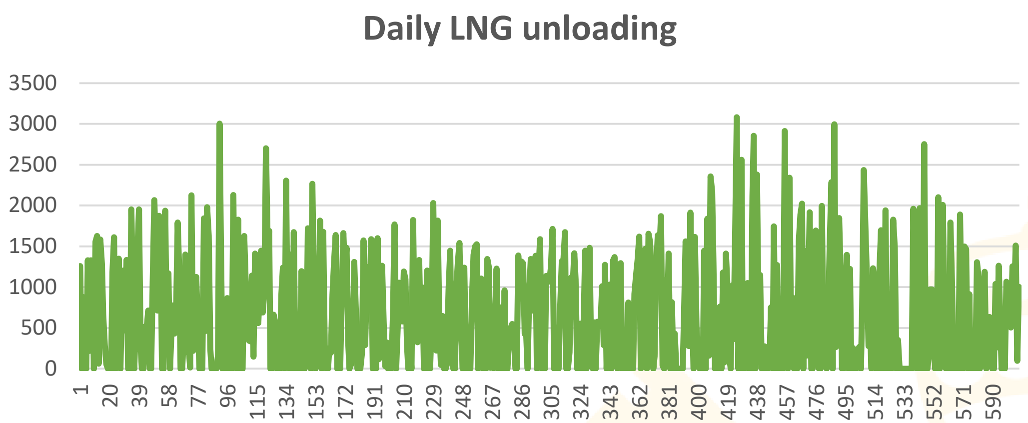
*Source: enagas spanish gas system report 2022

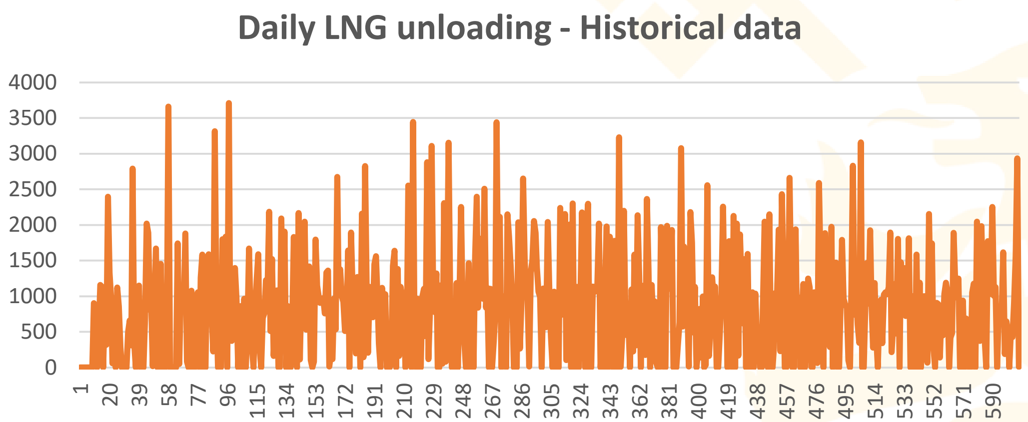
Results

Case 1: without two-step methodology



Case 2: two-step methodology





Conclusions

- The proposed methodology has proven effective in representing LNG carriers in particular and all other fundamentals (demand, contracts, etc.) relevant to the decision-making process in the gas market.
- This two-stage methodology is sufficiently robust to represent the dynamics of LNG carrier unloading realistically and consistently.

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Two-stage approach

Synthetic daily profile of LNG carriers unloading

Monthly volumes of LNG unloading

Daily volumes of LNG unloading

January year 1

Day	%
1	8%
2	0%
3	0%
4	4%
5	0%
6	7%
7	0%
8	5%
9	0%
10	4%
11	4%
12	4%
13	0%
14	9%
15	4%
16	7%

Day	%
17	1%
18	0%
19	4%
20	4%
21	1%
22	3%
23	2%
24	4%
25	5%
26	4%
27	0%
28	2%
29	2%
30	8%
31	5%
Total	**100%**

*

Month	LNG Volume
1	22000
2	18000
3	21500
4	19000
5	19500
6	17000
7	18500
8	19500
9	18000
10	19000
11	22000
12	23000

=

Day	LNG Volume
1	1658
2	0
3	0
4	918
5	0
6	1449
7	0
8	1090
9	0
10	876
11	916
12	818
13	64
14	1970
15	976
16	1592