



MASCEM

Multi-Agent Simulator of Competitive Electricity Markets

Overview

The Multi-Agent Simulator of Competitive Electricity Markets (MASCEM) [1], [2] is a simulation and modelling tool developed to study and simulate electricity market (EM) operations. It models the main market entities and their interactions. Medium/long-term gathering of data and experience is also considered to support players' decisions under their specific characteristics and goals. The main market entities are implemented as software agents, such as market and system operators, buyer and seller agents (consumers, producers, and/or prosumers), and aggregators.

The Market Operator regulates pool negotiations by validating and analysing the players' bids depending on the type of negotiation. It also determines the market price, the accepted and refused bids, and the economical dispatch that will be sent to the System Operator. The System Operator examines the technical feasibility from the power system's point of view and solves congestion problems that may arise. It is also responsible for the system's security as well as ensuring that all conditions are met within the system.

The key elements of EMs are Buyer and Seller agents. A Buyer agent may be a consumer or distribution company that participates in the market to buy given amounts of power. On the other hand, a Seller agent may simulate electricity producers or other entities allowed to sell energy in the market. Aggregators represent alliances of small independent players in order to enable their participation in the wholesale market and compete with bigger players. Aggregators manage their aggregates' information and are seen from the market's point of view as buyer or seller agents.

The main types of negotiations usually presented in the EM, that are included in MASCEM are day-ahead and intraday markets (symmetric or asymmetric, with or without complex conditions), bilateral contracts, and intraday markets. By selecting a combination of these market models, it is also possible to perform hybrid simulations. For each scenario, the user must input the market and market type to simulate, the number of simulation days, the number of participating players and their strategies considering each type of agent. MASCEM accommodates the simulation model of three of the main European EM: the Iberian EM (MIBEL), European Power Exchange (EPEX), and Nord Pool. Recently, in the scope of TradeRES project, the Pan-European Single Intraday Coupling (SIDC) has also been included in MASCEM.



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Inputs

In the scope of the TradeRES project, MASCEM allows the simulation of MIBEL day-ahead and intraday markets, EPEX and Nord Pool day-ahead markets and SIDC. It also simulates symmetric and asymmetric pools for a specific period. Inputs are passed using a JavaScript Object Notation (JSON) file for each specific type of simulation. Table E - 1 presents snippets with examples of the inputs required for MIBEL, EPEX, Nord Pool and SIDC. For each input a link to an online *schema* is provided.

Table E - 1. Snippets of input examples for simulating MIBEL, EPEX, Nord Pool, and SIDC.

MIBEL (schema)	<pre>{ "electricityMarket": { "marketType": "DAY_AHEAD", "sessionID": "1", "numberOfPeriods": 24, "numberOfOffersPerBid": 1, "playersBids": [{ "playerID": "Player 1", "bids": [{ "period": 1, "transactionType": "SELL", "offers": [{ "price": 25, "power": 100 }, ...] }, ...] }, ...], "complexConditions": { "indivisibility": true, "chargeGradient": 10, "minimumIncome": { "totalIncome": 100, "valuePerPowerUnit": 5, "scheduledStop": true } } } }, ...]</pre>
EPEX (schema)	<pre>{ "electricityMarket": { "sessionID": "1", "numberOfPeriods": 24, "numberOfOffersPerBid": 1, "playersBids": [{ "playerID": "Player 1", "bids": [{ "period": 1, "transactionType": "BUY", "offers": [{ "price": 25, "power": 100 }, ...] }, ...] }, ...], "blockOffers": [{ "price": 25, "power": 100 }] } }</pre>



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	<pre> "startPeriod": 1, "endPeriod": 3, "transactionType": "SELL" }, ...], }, ...]] }</pre>
Nord Pool (schema)	<pre>{ "electricityMarket": { "sessionID": "1", "numberOfPeriods": 24, "numberOfOffersPerBid": 2, "playersBids": [{ "playerID": "Player 1", "bids": [{ "period": 1, "transactionType": "BUY", "offers": [{ "price": 20, "power": 100 }, ...] }, ...], }, ...], "blockOrders": [{ "price": 25, "power": 100 "startPeriod": 1, "endPeriod": 3, "transactionType": "BUY" }, ...], "flexibleOrders": [{ "price": 25, "power": 25, "transactionType": "SELL" }, ...] }, ... }</pre>
SIDC (schema)	<pre>{ "sob": { "day": "2023-01-01", "opening": "14:00:00", "closure": "15:00:00", "round": 17, "tradingPeriod": { "startTimeStamp": "2022-12-31 16:00:00", "endTimeStamp": "2023-01-01 00:00:00" }, }, "config": { "size": { "value": 0.1, "unit": "MWh" }, "priceTick": { "value": 0.01, "unit": "EUR/MWh" }, "volumeRange": { "minimumValue": 0.1, "maximumValue": 999, "unit": "EUR/MWh" } } }</pre>



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```
    },
    "priceRange": {
      "minimumValue": -9999,
      "maximumValue": 9999,
      "unit": "EUR/MWh"
    },
    "products": {
      "id": "hourly",
      "duration": "PT1H"
    }
  }
},
"orders": [
  {
    "contract": {
      "startTimeStamp": "2023-01-01 16:00:00",
      "endTimeStamp": "2023-01-01 17:00:00"
    },
    "price": {
      "value": -0.01,
      "unit": "EUR/MWh"
    },
    "energy": {
      "value": 20,
      "unit": "MWh"
    },
    "energyPeakSize": {
      "value": 10,
      "unit": "MWh"
    },
    "pricePeakDelta": {
      "value": 0,
      "unit": "EUR/MWh"
    },
    "timeStamp": "2023-01-01 14:00:00",
    "round": 17,
    "productID": "hourly",
    "zone": "10YES-REE-----0",
    "agent": "SOREX",
    "unit": "SORXC01",
    "transactionType": "sell",
    "executionCondition": "ICE",
    "validityCondition": "GTD"
  },
  ...
]
```

The “marketType” property of MIBEL accepts one of the constants: “DAY_AHEAD” or “INTRADAY”. The “complexConditions” (MIBEL), “blockOffers” (EPEX & Nord Pool), and “flexibleOffers” (Nord Pool) properties are optional for each respective EM [3], [4]. The user must uniform the “price” and “power” units. In the context of SIDC simulations, it is characterized by establishing limits on energy and price transactions using “energyPeakSize” and “pricePeakDelta”, defining “executionCondition” to pre-set trading conditions (“NON”, “ICE/ICE_PI”, “IOC”, “FOK”, and “AON”), and applying “validityCondition” to scrutinize bids: “GTD” or “GFS”. Table E - 2 shows input examples for the symmetrical and asymmetrical pools respectively. The only difference between them is that, in the asymmetrical pool, only sellers are able to submit prices in their bids [5]. The “instant” property allows to order the bids by order of submission when there is no “price” or when there are multiple offers with the same “price”.



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Table E - 2. Snippet of input examples for running asymmetrical and symmetrical pool algorithms.

Asymmetrical Pool (schema)	Symmetrical Pool (schema)
<pre>{ "demandBids": [{ "offerUUID": "Player1Period1", "energy": 0.0621, "instant": 1493641594783 }, ...], "supplyBids": [{ "offerUUID": "Player9Period1", "energy": 1.987, "price": 0.0998, "instant": 1493642533688 }, ...] }</pre>	<pre>{ "demandBids": [{ "offerUUID": "Player1Period1", "energy": 0.0621, "price": 0.1827, "instant": 1493641594783 }, ...], "supplyBids": [{ "offerUUID": "Player9Period1", "energy": 1.987, "price": 0.0998, "instant": 1493642533688 }, ...] }</pre>

After the market's execution, the power flow validation of the electrical grid's technical feasibility is simulated. Table E - 3 presents a snippet of the power flow validation input.

Table E - 3. Snippet of power flow input example.

Power Flow (schema)
<pre>{ "network": { "name": "Spine 1", "elements": { "buses": [{ "id": 0, "busName": "bus 1", "voltage": 12 }, ...], "lines": [{ "id": 6, "name": "line 1", "initialBus": 0, "finalBus": 1, "length": 21, "lineCapacitance": 1.5, "lineReactance": 1.4, "lineResistance": 1.4, "zeroSequenceLineCapacitance": 1.1, "zeroSequenceLineReactance": 1.2, "zeroSequenceLineResistance": 1.3, "maximumThermal": 11 }, ...] } }, "externalGrids": [{ "id": 10, "name": "external grid 1", "bus": 1, "controllable": true, "degree": 20, "inService": true, "maxActivePower": 100, "maxReactivePower": 100, "maxRXRatio": 100, "maxShortCircuitApparentPower": 100, }] }</pre>



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```
    "minActivePower": 100,  
    "minReactivePower": 100,  
    "minRXRatio": 100,  
    "minShortCircuitApparentPower": 100,  
    "voltage": 100,  
    "zeroSequenceMaxRXRatio": 100,  
    "zeroSequenceMaxX0XRatio": 100  
  }  
}  
},  
"powerflow": {"balancedAC": {}},  
"resultType": "json"  
}
```

The mappings between market players and the grid are performed as demonstrated below.

Table E - 4. Snippet of Player(s)-Bus(es) mappings.

Player-Bus Mapping

```
{  
  "playersBuses": [  
    {  
      "player": "Player 1",  
      "bus": 0  
    },  
    ...  
  ]  
}
```



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Outputs

MASCEM's outputs, in turn, depending on what we are simulating, may assume three forms, as demonstrated below.

Table E - 5. Snippets of output examples for each market type.

<p>MIBEL, EPEX, & Nord Pool (Session)</p>	<pre>{ "status": "ok", "message": { "market": "MIBEL", "marketType": "SPOT", "session": { "totalDemandByPeriodOffers": 4700.0, "totalSupplySatisfied": 4600.0, "session": 1, "socialWelfare": 2500.0, "totalSupplyByPeriodOffers": 4600.0, "totalSupply": 4600.0, "playersResult": [{ "playerPeriodsResult": [{ "transactionType": "buying", "costs": 2500.0, "period": 1, "marketPrice": 25.0, "satisfied": 100.0, "demand": 100.0 }, { "removalJustification": "Player 1 removed from exchange because of indivisibility condition!", "period": 2 }], ... }, ...], "totalDemandSupply": 2400.0, "totalCostsProfits": 60000.0, "totalSatisfied": 2400.0, "totalCostsProfitsByPeriodOffers": 60000.0, "demandSupplyByPeriodOffers": 2400.0, "playerId": "Player 1" }, ...], "consumptionSurplus": 2500.0, "demandSatisfiedByPeriodOffers": 4600.0, "averageMarketPrice": 25.0, "totalDemand": 4700.0, "totalDemandSatisfied": 4600.0, "generationSurplus": 0, "supplySatisfiedByPeriodOffers": 4600.0, "periods": [{ "period": 1, "totalDemandByPeriodOffers": 150.0, "totalDemand": 150.0, "totalSupplySatisfied": 100.0, "socialWelfare": 0, "totalSupplyByPeriodOffers": 100.0, "totalSupply": 100.0, "totalDemandSatisfied": 100.0, "generationSurplus": 0, "supplySatisfiedByPeriodOffers": 100.0, "consumptionSurplus": 0, "demandSatisfiedByPeriodOffers": 100.0 }, ...] } }</pre>
<p>SIDC (Session)</p>	<pre>{ "status": "ok", "message": { "matched": [</pre>



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```
{
  "buy": {
    "uuid": "a01249b0-5be5-4300-a74f-e23bcea617de",
    "contract": {
      "startTimeStamp": "2023-01-01 16:00:00",
      "endTimeStamp": "2023-01-01 17:00:00"
    },
    "price": {
      "value": 30.92,
      "unit": "EUR/MWh"
    },
    "energy": {
      "value": 5.4,
      "unit": "MWh"
    },
    "energyPeakSize": {
      "value": 0,
      "unit": "MWh"
    },
    "pricePeakDelta": {
      "value": 0,
      "unit": "EUR/MWh"
    },
    "timeStamp": "2023-01-01 14:02:38",
    "round": 17,
    "productID": "hourly",
    "zone": "10YES-REE-----0",
    "agent": "EGED",
    "unit": "EGEDRE6",
    "transactionType": "buy",
    "executionCondition": "",
    "validityCondition": "GTD"
  },
  "sell": {
    "uuid": "2a8312cf-409e-499f-bd78-3d38beb91415",
    "contract": {
      "startTimeStamp": "2023-01-01 16:00:00",
      "endTimeStamp": "2023-01-01 17:00:00"
    },
    "price": {
      "value": -0.01,
      "unit": "EUR/MWh"
    },
    "energy": {
      "value": 5.4,
      "unit": "MWh"
    },
    "energyPeakSize": {
      "value": 10,
      "unit": "MWh"
    },
    "pricePeakDelta": {
      "value": 0,
      "unit": "EUR/MWh"
    },
    "timeStamp": "2023-01-01 14:00:00",
    "round": 17,
    "productID": "hourly",
    "zone": "10YES-REE-----0",
    "agent": "SOREX",
    "unit": "SORXC01",
    "transactionType": "sell",
    "executionCondition": "ICE",
    "validityCondition": "GTD"
  },
  "matchedPrice": {
    "value": 0,
    "unit": "EUR/MWh"
  },
  "matchedEnergy": {
    "value": 5.4,
    "unit": "MWh"
  }
},
...
],
"unmatched": {
  "buy": [
    {
```




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```
    "uuid": "00d75a74-6d5c-4f02-8347-f7837cb8c63d",
    "contract": {
      "startTimeStamp": "2023-01-01 16:00:00",
      "endTimeStamp": "2023-01-01 17:00:00"
    },
    "price": {
      "value": -4,
      "unit": "EUR/MWh"
    },
    "energy": {
      "value": 4,
      "unit": "MWh"
    },
    "energyPeakSize": {
      "value": 0,
      "unit": "MWh"
    },
    "pricePeakDelta": {
      "value": 0,
      "unit": "EUR/MWh"
    },
    "timeStamp": "2023-01-01 14:08:41",
    "round": 17,
    "productID": "hourly",
    "zone": "10YES-REE-----0",
    "agent": "SHEEN",
    "unit": "SHEVD03",
    "transactionType": "buy",
    "executionCondition": "",
    "validityCondition": "GTD"
  },
  ...
],
"sell": [
  {
    "uuid": "2fd6ead6-3175-4e17-8ea7-48c097a3276e",
    "contract": {
      "startTimeStamp": "2023-01-01 16:00:00",
      "endTimeStamp": "2023-01-01 17:00:00"
    },
    "price": {
      "value": 1.09,
      "unit": "EUR/MWh"
    },
    "energy": {
      "value": 10.5,
      "unit": "MWh"
    },
    "energyPeakSize": {
      "value": 6,
      "unit": "MWh"
    },
    "pricePeakDelta": {
      "value": 0,
      "unit": "EUR/MWh"
    },
    "timeStamp": "2023-01-01 14:02:35",
    "round": 17,
    "productID": "hourly",
    "zone": "10YES-REE-----0",
    "agent": "EGED",
    "unit": "EGEDRE3",
    "transactionType": "sell",
    "executionCondition": "ICE",
    "validityCondition": "GTD"
  },
  ...
]
}
}
{
  "status": "ok",
  "message": {
    "marketPrice": 0.1598,
    "hasTrading": true,
    "tradingResults": [
      {
        "offerUUID": "Player10Period57BidOffer",
```

**Asymmetrical &
Symmetrical
Pools (Period)**



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```
    "wasTraded": true,  
    "transactionType": "buy",  
    "price": 0.1827,  
    "energy": 0.0621,  
    "tradedEnergy": 0.0621  
  },  
  ...  
],  
"totalDemand": 20.4421,  
"totalSupply": 2.7837000000000005,  
"poolResult": "TRADING",  
"totalTradedEnergy": 2.6027000000000005,  
"lastTradedSupplyOffer": "Player12Period57BidOffer",  
"lastTradedDemandOffer": "Player5Period57BidOffer"  
}  
}
```

It should be noticed that these results are in the perspective of the market operator agent, who then sends the individual results to each participating player. Table E - 6 presents a snippet of a power flow output example.

Table E - 6. Snippet of Power Flow output.

Power Flow

```
{  
  "results": {  
    "buses": {  
      "vm_pu": {"0": 1.0, ...},  
      "va_degree": {"0": 0.0, ...},  
      "p_mw": {"0": 242.4489795918, ...},  
      "q_mvar": {"0": 242.4496921051, ...}  
    },  
    "lines": {  
      "p_from_mw": {"0": -242.4489795918, ...},  
      "q_from_mvar": {"0": -242.4496921051, ...},  
      "p_to_mw": {"0": 24244.8979591837, ...},  
      "q_to_mvar": {"0": 24237.7728270453, ...},  
      "pl_mw": {"0": 24002.4489795918, ...},  
      "ql_mvar": {"0": 23995.3231349403, ...},  
      "i_from_ka": {"0": 16.4965878141, ...},  
      "i_to_ka": {"0": 15.2253597533, ...},  
      "i_ka": {"0": 16.4965878141, ...},  
      "vm_from_pu": {"0": 1.0, ...},  
      "va_from_degree": {"0": 0.0, ...},  
      "vm_to_pu": {"0": 100.0, ...},  
      "va_to_degree": {"0": 0.0, ...},  
      "loading_percent": {"0": 149.9689801278, ...}  
    },  
    "loads": {  
      "p_mw": {"1000": 100.0, ...},  
      "q_mvar": {"1000": 0.0, ...}  
    },  
    "externalGrids": {  
      "p_mw": {"0": -142.4489795918, ...},  
      "q_mvar": {"0": -242.4496921051, ...}  
    },  
    ...  
  }  
}
```



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How to run it

MASCEM's project within the Spine Toolbox (publicly available [here](#) for download) provides the simulation of MASCEM's EMs models and power flow models. This specific project is prepared to execute the Iberian electricity market – MIBEL – and validate the power network constraints, according to the market results. The Toolbox workflow is shown in Figure E - 1. This project only requires the installation of Python's JSON package.

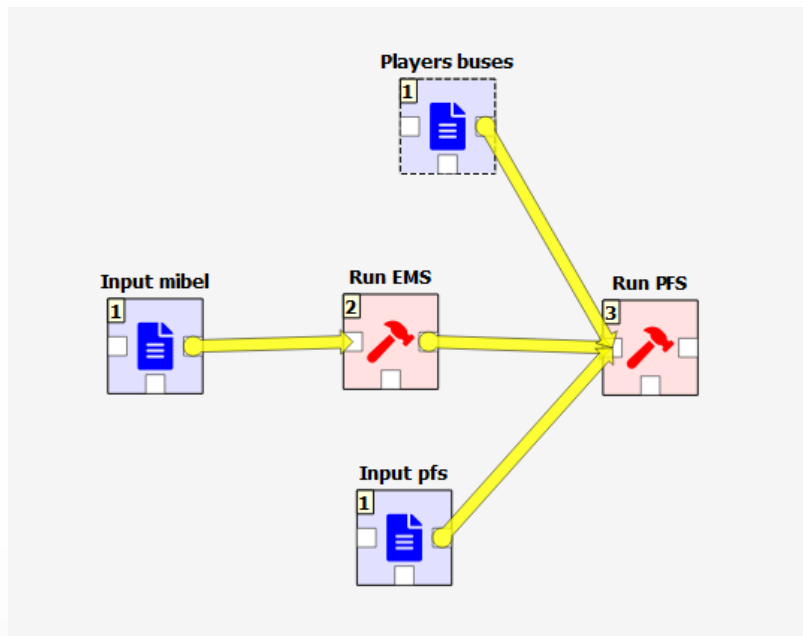


Figure E - 1. MASCEM's Spine Toolbox project workflow.

There are five components inside the MASCEM Demo Spine Toolbox project:

- **Input mibel** is the input of the **Run EMS** component and contains information regarding the players and their price/amount bids for each period. The schema that validates this input is available at [./run-ems/resources/generalSchema.json](#). The market input file must be placed in the run-ems folder. An example file is publicly available [here](#).
- **Player buses** ([schema](#)) is one of the inputs of the **Run PFS** component. This file maps the players present in the MIBEL market to the buses of the network defined in the **Input pfs**.
- **Input pfs** is one of the inputs of the Run PFS component and contains information regarding the elements of the network, as well as the power flow algorithm to be used and its parameters. The schema that validates this input is available at [./run-pfs/resources/pfs_schema.json](#). The power flow input file must be placed in the run-pfs folder. An example file is publicly available [here](#).
- **Run EMS** executes the MIBEL day-ahead market (defined in the input of the previous component), validating it with the [JSON schema](#) created to verify the



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structure of the JSON input. The results of simulating the MIBEL market are then sent to the **Run PFS** tool.

- **Run PFS** executes the Power Flow service receiving the network, the power flow algorithm to be used and the loads of each bus by mapping the players' results to the buses. It also validates the **Input pfs** with the [JSON schema](#) created to verify the structure of the JSON input. The results are then saved in a JSON file.

After execution, output files are saved in dynamically generated folders named in the forms:

- **Run EMS:** run-ems/output/YYYY-MM-DDTHH.mm.ss
- **Run PFS:** run-pfs/output/YYYY-MM-DDTHH.mm.ss



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Find out more

[1] Gabriel Santos, Tiago Pinto, Isabel Praça, Zita Vale, "MASCEM: Optimizing the performance of a multi-agent system", Energy, vol. 111, pp. 513-524 (2016). DOI: [10.1016/j.energy.2016.05.127](https://doi.org/10.1016/j.energy.2016.05.127).

[2] Tiago Pinto, Zita Vale, Isabel Praça, Luis Gomes, Pedro Faria, "Multi-Agent Electricity Markets and Smart Grids Simulation with connection to real physical resources". In "Electricity Markets with Increasing Levels of Renewable Generation: Structure, Operation, Agent-based Simulation and Emerging Designs". F. Lopes, H. Coelho (Eds). Springer Int. Publishing (2018).

[3] Gabriel Santos, Tiago Pinto, Hugo Morais, Isabel Praça and Zita Vale, "Complex market integration in MASCEM electricity market simulator," 2011 8th International Conference on the European Energy Market (EEM), Zagreb, Croatia, 2011, pp. 256-261. DOI: [10.1109/EEM.2011.5953019](https://doi.org/10.1109/EEM.2011.5953019).

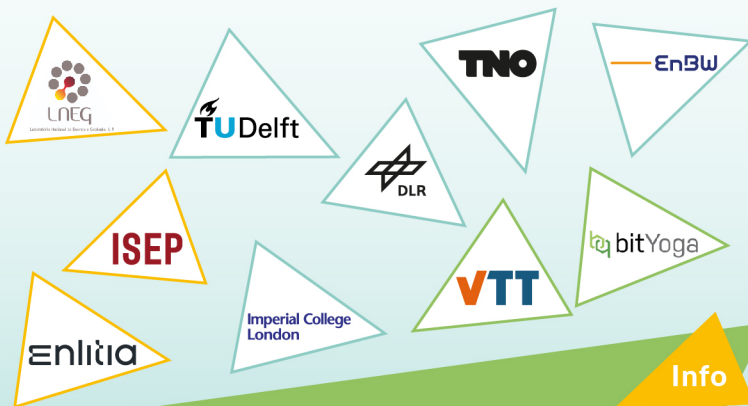
[4] Gabriel Santos, Tiago Pinto, Zita Vale, Hugo Morais, and Isabel Praça, "Balancing market integration in MASCEM electricity market simulator," 2012 IEEE Power and Energy Society General Meeting, San Diego, CA, USA, 2012, pp. 1-8. DOI: [10.1109/PESGM.2012.6345652](https://doi.org/10.1109/PESGM.2012.6345652).

[5] Isabel Praça, Carlos Ramos, Zita Vale and Manuel Cordeiro, "MASCEM: A Multi-Agent System that Simulates Competitive Electricity Markets", IEEE Intelligent Systems, vol. 18, No.6, pp. 54-60, Special Issue on Agents and Markets, 2003.

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Info

The TradeRES project will develop and test innovative electricity market designs that can meet society's needs of a (near) 100% renewable power system. The market design will be tested in a sophisticated simulation environment in which real-world characteristics such as actors' limited foresight into the future and risk aversion are included.



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