ODD protocol
Investor-based electricity market model

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1. Introduction

In this protocol the ABM model on investor behaviour in the electricity system will by described using the ODD protocol standards. The ODD protocol, developed by (Grimm et al., 2010, 2006), is used to standardise the published descriptions of individual-based and agent-based models (ABMs). ODD stands for Overview, Design Concepts and Details, the three main categories of the protocol. In the first category, an overview of the overall purpose and structure of the model is provided. Readers can very quickly get an idea of the model's focus, resolution and complexity. Furthermore, the overview provides a description of the entities and state variables included in the model, as well as the spatial and temporal scales and extents. The second category, design concepts, describes the general concepts underlying the design of the model according to general characteristics of ABM's. The design concepts can be seen as a kind of checklist to make sure that important model design decision are made consciously and that readers are aware of these decisions. The third element includes three elements (initialisation, input data and submodels) provide the more technical details of the model, that were omitted in the overview. An overview of the different elements within the ODD protocol is provided in Table 1. (Greeven, 2015)

Table 1: ODD protocol **(Grimm et al., 2010)**

Overview	Purpose Entities, state variables, and scales Process overview and scheduling
Design concepts	Design concepts • Basic principles • Emergence • Adaptation • Objectives • Learning • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation
Details	Initialisation Input data Submodels

In this ODD-protocol the agent-based model about the energy transition from an investors point of view is presented. The model has been used to describe fundamental dynamics of the electricity market which results will be published in a yet to be submitted paper. In this ODD protocol no references are given to specific sources of data, they are mentioned in.

2. Overview

2.1. Purpose

The goal of this study is to elucidate the fundamental processes that underline the transition of the electricity system. We have taken a conceptual approach that was aimed at a minimum set of agent-types, behaviour rules and assumptions that could replicate the fundamental dynamics of the first phase of the transition and show possible concerns for the future. This approach has strengthened the transparency, tractability and reproducibility of model results as these are three fundamental challenges in agent-based modelling studies Entities, state variables, and scales

2.2. Entities, state variables, and scales

The section describes the agents in the model, by defining the state variables and attributes that characterise these agents. Furthermore, this section will elaborate on the temporal and spatial resolutions and extents of the model.

Agents and their state variables

The model is an abstract and conceptual representation of the electricity market and consists of two types of agents, large scale investors in the electricity sector and electricity producing assets. At initialization the number of investors and assets describes the situation in the Netherlands in order of magnitude (5 investors, 20 assets of 1 GW). During the model run, each year a predefined number of new investors can enter the market with heterogeneous discount rate.

Investors are large scale investors that can decide based on economic considerations, to invest in power generation assets with a fixed set capacity of one GW. Every year they make Net Present Value (NPV) calculations based on heterogeneous discount rates and the investors' expectation about how these assets will perform in the future. They can choose between 100% coal or gas based units or units that rely on renewables such as large offshore wind parks. In making these predictions about the future they rely on last year electricity market performance.

Table 2 shows the fixed and variable attributes for investors and assets. At initialization assets have a heterogeneous age and efficiency, resource and lifetime (depending on its resource); investors are initialized with a heterogeneous discount rate within threshold values.

Table 2. Agents attributes

State variable	Fixed attributes	Properties
Investors		
Fixed		
IDI	Identity number of the investor	Integer > 0
Variable		
R	Discount rate, random between	Floating point

	threshold values, see chapter … Discount rate.	
NPVG/NPVR/NPVG, discountlistgas/coal/r, expectprofitcoallist/gaslist/Rlist, discountedexpectprofitgaslist/coallist/Rlist, CBgas/coal/r	Parameters to calculate NPV of coal, gas or renewable (r) assets.	Floating point, list of floating points
Averageprofitability, averageprofitabilityperasset, sumprofitability	Parameters to assess profitability of assets owned by the investor. Parameters are used to adjust discount rate of the investor.	Floating point
Investmentmade?	Parameter to assess if an investment has been made	Boolean
New?	Parameter to assess if an investor has been created this year	Boolean
Iassetlist	List of assets owned by the asset	List of agents
Assets		
Fixed		
Capacity	Capacity in GW	Integer > 0
Resource	Which resource does the asset use	String: “gas”, “coal”, “renewable”
SRMC	Short Run Marginal Costs, depends on efficiency and fuel, see chapter … SRMC.	Floating point
SRMCfactor	Efficiency factor that is given to an asset at creation. Depends on the year of creation, or its age at initialisation.	Floating point
Lifetime	Lifetime of asset, set equal to the maximum lifetime of an asset with a particular resource: maxagegas/coal/R.	Integer > 0
IDlinkedinvestor	Identify of investor that asset belongs to	Integer > 0
Yearstoproduction	Number of years before the asset will produce. Set equal to gasleadtime / coalleadtime at initialization of the asset.	Integer >= 0
Variable		
Price resource	Externally determined price of its resource	Floating point
Age	Age of asset	Integer > 0
profitlist	List of profits made in a year	List of floating points
profitability	Profitability of the asset	Floating point
IDA	ID of the asset	Integer > 0
profit	Profit made in a specific time periode	Floating point

new?A	Boolean to indicate if the asset is new this year	Boolean
Productionbyassetlist, productionbyasset	Production by asset in a specific tick, list of production	Floating point, list of floating points
capacityfactorofasset	Capacity factor of the asset	Floating point
numberoflinksA	Number of investors the asset is owned by (should be one)	Integer

Discount rate

All investors evaluate opportunities by assessing the discounted cash flows in relationship with the size of the investment. The combination of the heterogeneous external expectations (e.g. future prices) and internal requirements investors have (e.g. related to their risk profile), determines the discount rate with which they evaluate these cash flows.

Based on the development of the electricity market and the choices investors have made, these investors evaluate their performance. Their performance is reflected in the average profitability of the assets an investor owns. In general, they will find it harder to borrow money from financial markets when their profitability has decreased and vice versa.

Table 3 Discount rate

State variable	Description	Properties
Discount rate		
Highaverageprofitabilitythreshold	Upper threshold	Floating point > 0
Averageprofitabilityfraction	Parameter to calculate lower threshold. Multiplied with highaverageprofitabilitythreshold gives lower threshold	Floating point > 0
Discountrateincrease	Variable to increase discount rate of the investors if profitability threshold is passed	Floating point > 0
discountratedecrease	Variable to increase discount rate of the investors if profitability threshold is passed	Floating point > 0
Initialisation		
Maxr	Upper threshold in the discount rate range	Floating point > 0
Rfraction	Parameter to calculate lower threshold in discount rate range. Multiplied with maxr gives lower threshold.	Floating point > 0
drfloor	When profitability is high enough, the discount rate of the investors lowers, but it cannot go lower than drfloor.	Floating point > 0

SRMC and efficiency improvement

The short run marginal costs (SRMC) of an asset are determined on the efficiency of the asset, the resource the asset uses.

$$SRMC = SRMCfactor * priceresource$$

For a gas asset, the SRMCfactor would be equal to:

$$SRMCfactor = (1 - (\frac{efficiencyimprovementG}{100}))^{(lifetimegas + y)}$$

$$priceresource = pricegas$$

$$pricegas = FCC + \frac{(carbonintensitygas * carbonprice)}{specificenergygas} * \frac{1}{basicefficiencygas} * 1000 * 3.6$$

Although fossil electricity production units exist for a long time, the assumption is that new units have a slightly higher than older units. The efficiency improvement can be set separately for gas and coal assets in the interface. A new unit, with a slightly higher efficiency, will therefore be placed in front of the current most profitable unit (with the same resource) in the merit order. The expected profits of a new unit will therefore correspond to the profit the existing unit made in the last year multiplied by the lifetime asset. The efficiency of an asset is calculated at creation of the asset and remains static.

Table 4 SRMC

State variable	Description	Properties
Variable		
FCC	Fuel costs for coal (euro/ton)	Floating point > 0
FCG	Fuel costs for gas (€/m^3)	Floating point > 0
Carbonintensitygas/coal	Carbon intensity for gas/coal	
Specifenergygas/coal	Specific energy gas/coal	
efficiencyimprovementG/C	Efficiency improvement per year for new gas/coal assets. (%)	Floating point > 0, < 100
Basicefficiencygas / coal	Efficiency of gas/coal asset at initialisation, taken into account the heterogeneous age of assets at initilisation.	Floating point > 0, < 1

Spatial representation of the system

The visualization of the model displays how the three types of assets (green = renewable, blue = coal, red = gas) are connected to their investors (new investors are purple). This is for mere visualization, as the model has a limited spatial character. Interface shows investors and their connected assets but is only used as illustration for the model process.

Environment

Electricity market

In the model investors and assets are part of the electricity market. In the electricity market, assets produce electricity and investors can decide to build new generation capacity. The electricity market is modelled as Energy-Only market where the electricity price is determined by supply and demand. Demand is kept constant to increase tractability of the model. Electricity price is determined in the merit order by the SRMC of the marginal producer plus a scarcity rent. The scarcity rent is determined via the relationship between the scarcity rent and the excess capacity-factor. This excess capacity factor is defined in equation 3 as the potential power generation of all assets i.e. the summation of the potential power supply from coal and gas assets (1 GW) and the variable power supply from renewable assets and can also be expressed as the formally known adequacy margin (i.e. 1- e(t)).

$$S\ (t) = \frac{S_{max} - S_{min}}{\alpha\ - 1} * \alpha^{e(t)} + S_{min} - \left(\frac{S_{max} - S_{min}}{\alpha\ - 1}\right)$$

S(t) = Scarcity rent at time t
Smin= Minimum scarcity rent
Smax = Maximum scarcity rent
α = Scarcity rent variable that determines curvature
e(t) = excess capacity factor at time t defined by

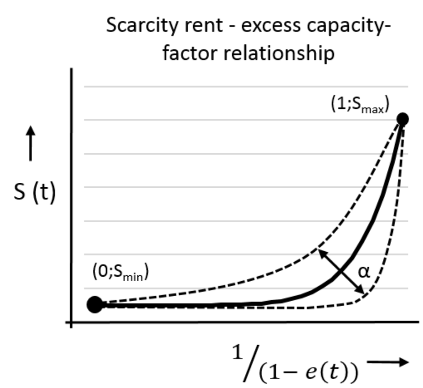

Figure 1. Relationship between scarcity rent and excess capacity factor

$$e(t) = \frac{\sum P(t)_{ren} + \sum P(t)_{gas} + \sum P(t)_{coal}}{D}$$

D = (Constant) demand
$P(t)_i$ = Potential production at time t of all assets with resource i, including the variability of renewable assets in $P(t)_{ren}$

The scarcity rent is zero if enough capacity is available as no market player can use their market power to raise the price. On the other hand, the scarcity rent should be high at moments capacity is scare to incentivize investment (and reflects the value of lost load). The relationship between the scarcity rent and the excess capacity factor comes is defined under the restriction that outages are not allowed to occur. We found that a scarcity rent – excess capacity factor relationship should start at zero and allowed to run up to at least 100 with an α of 1.5.

Investors and assets are part of the electricity market, the environment of the agents. External factors that influence the behaviour of investors and assets are the resource prices and the demand and supply of electricity. In this market, assets produce electricity based on electricity demand and investors can decide to build new generation capacity. The interaction between investors runs via the electricity market.

Every tick, which represents the shortest time unit (e.g. a second, day or season) electricity prices are calculated. The electricity price is determined by demand and supply in the merit order where the marginal producer sets the price. The merit order is calculated with the short run marginal costs (SRMC) of all existing assets. The SRMC costs for fossil units are calculated on a day to day basis and are based on exogenous determined coal and gas prices, specific energy and efficiency of the different assets, the SRMC of green power generation are assumed to be zero, OPEX costs are neglected.

Table 5. Scarcity rent

State variable	Description	Properties
Variable		
Averagecapacityfactor	Demand divided by capacity	Floating point > 0
Initialisation		
SRdynamics	Choser between two functions: SRlinearfunction, SRthreshold	String: “SRlinearfunction”, “SRfunction”
SRdynamics: “SRthreshold”		
SRhighthreshold	Upper threshold averagecapacityfactor. If averagecapacityfactor surpasses this threshold, SR changes.	Floating point > 0
SRinit	SR at initialisation	Floating point > 0
SRthresholdfraction	Parameter to calculate lower threshold of averagecapacityfactor.	Floating point > 0
SRincrease	Parameter that will be added to SR is threshold is passed	Floating point > 0
SRdecrease	Parameter that will be substracted from SR is threshold is passed	Floating point > 0
SRdynamics: “SRlinearfunction”		
SRdecreasebase	Minimum SR decrease	Floating point > 0
SRRico	Factor of the proportionally increase/decrease	Floating point > 0
SRincreasebase	Minimum SR increase	Floating point > 0
lowestSR	Minimum SR	Floating point > 0
outagebonus	If an outage occurs, outagebonus is added to the SR.	Floating point > 0
SRdynamics: “SR-CF”		
v.begin	Scarcity rent when capacity factor is 0	Floating point > 0

v.eind	Scarcity rent when capacity factor is 1	Floating point > 0
v.slope	Variable that determines the curve of the function	Floating point > 0, <1
Steps	Scale factor	Integer > 0

Carbon price policy

A carbon price can be adopted by governments influencing investment decisions by investors. Three different policies can be implemented; a static carbon price which is constant over the runtime of the model; a linear increasing carbon price; and e endogeneous carbon price which increases proportional to the goal set.

Table 6. Carbon price policy

State variable	Description	Properties
Variable		
Initialisation		
Carbonpricefunction	Three different policies can be chosen: Linear increasing carbonprice over time, fixed carbon price for the whole time period, a specific carbonprice scenario (base case), dynamic carbonprice where a decarbonisation target in a specific year is set and the carbon price is a function of the difference between the set target and the actual decarbonisation percentage, weighted over the time left to reach to goal.	Chooser
Carbonpricemanual	carbonpricemanual gives the carbonprice during the modelrun	Floating point > 0
Carbonmax	carbonmax give the carbonprice at the end of the runtime	Floating point > 0
Carbonfraction	carbonfraction gives the carbonprice at initialisation by calculating: carbonmin = carbonfraction * carbonmax	Floating point > 0
Renewableendgoal	If carbonpricefunction is set to dynamic	Floating point > 0
endtargetyear	endtargetyear is the year in which the target should be reached	Floating point > 0
carbonfactor	Carbonfactor is the weightfactor of the difference between the set	Floating point > 0

	goal, number of years to reach the target and difference between set target and actual realisation.	
Carbonpricemidway	The amount of years, the carbon price should increase.	Floating point > 0
Carbonpriceincrease	The amount the carbon price needs to increase every year.	Floating point > 0
Performance		
Renewabletarget	Goal set by the government for the decarbonisation of the electricity sector	
Targetyear	Year in which the set target for decarbonisation must be reached	

Learning rate of renewable technology

Renewable energy technology have shown large cost reduction the last decades. These costs have gone down in terms of euro's per GWpeak as wind turbines and photovoltaic cells have shown large cost reduction over the last couple of years. This reduction in turnkey costs can be explained by learning by doing which is a common known process where we see that unit costs follow learning curves and costs go down over cumulative investment. Onshore wind power generators have shown a learning rate of 9% while solar pv panels have shown learning rate of around 20 % percent per year.

In the model a choice can be made to include "learning by doing" in the investment price of renewables. If the variable chooseRenewableinvestment is set to dynamic, the investment in renewables at initialistion is set by IRbegin. If investments in renewable technology are made, the investment prices goes down following an exponential curve that ends at IRend with curve-variable IRvar.

Learning curve

State variable	Description	Properties
Initialisation		
ChooseRenewableinvestment	Choser to determine if investment costs are fixed or dynamic	"fixed", "dynamic"
IRbegin	Investment costs of renewable assets at initialisation	Floating point > 0
IRend	Minimum investment costs	Floating point > 0
IRvar	Variable that determines the learning curve	Floating point >0, <1

Variable production by renewable assets

Minimum power output of renewable power generations assets has been varied from 0 GW to 1 GW. Power output has been modelled as cosinus.

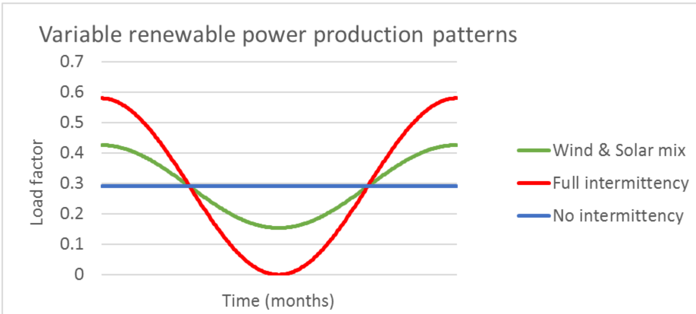

Figure 2 Variability of renewable power output

Intermittency

State variable	Description	Properties
Initialisation		
Min.R.power	Minimum power output of renewable asset	Floating point > 0
Periode	Period of the cosine function that describes the power output of a renewable asset	Floating point > 0
n.steps	Number of intervals within a year in which the output of renewables is averaged.	Integer > 0

Time formalisation

The model runs 100 years, representing the twenty-first century. Each year is divided in a predefined number of ticks, which represent the shortest time unit (e.g. second/days/weeks/seasons) which depends on the runtime the user allows and the time resolution the user demands.

Investors each year make an investment decision. The electricity market in which asset are positioned is updated every tick so that production and profits made by the assets are calculated every tick.

2.3. Process overview and scheduling

Initialisation

A predefined number of investors and assets are created and attributes are distributed. The predefined number of assets with a particular resource is randomly spread among the investors, the number of assets is uniform.

A visualistion of the models is created.

Initialisation

State variable	Description	Properties	Uncertainty range
Initialisation			
Numberofinvestors	Number of investors at initialisation	Integer > 0	Fixed 5
maxnewinvestorspertick	Number of new investors that can enter the market after a year	Integer > 0	Fixed 1
Initcapacity	Number of assets (and capacity) at initialisation	Integer > 0	Fixed 20
Percentagecoal / percentagegas / percentageR	Percentage coal, gas and renewable assets at initialisation	Floating point > 0, < 1	Fixed 0.75 / 0.25 / 0
DemandD	Demand		Fixed 15
Renewablesatinitialisation?	Variable that determines if there can be renewables at initialisation	Boolean	Fixed false
Maxagegas/coal/R	Maximum age of the gas/coal and renewable assets at initilisation	Integer > 0	Fixed 30/30/25
agefractionC/G/R	Parameter to calculate lower age limit	Integer > 0	Fixed 0.5
Daysinyear	Number of days in a year, shortest time unit in the model	Integer > 0	Fixed 12, months
Maxyears	Runtime of the model, expressed in years.	Integer > 0	Fixed 65
Runthroughoutage?	Variable to assess if the model allows outages (demand > supply)	Boolean	Fixed true
SRinit	SR at initialization	Floating point > 0	Fixed: 0.332
Lifetimegas/coal/R	Lifetime of a gas, coal or renewable asset	Integer > 0	Fixed 30
Carbonprice	The prices of carbon (€/ton)	Floating point > 0	
FCC	Fuel costs for coal (euro/tonne)	Floating point > 0	Fixed: 40
FCG	Fuel costs for gas	Floating point >	Fixed: 0.06

	(€/m^3)	0	
InvestmentG/C	Size of investment in gas/coal asset (in mld euro's).	Floating point	Fixed 0.7 / 1.2
InvestmentRset			
Maxassets	Maximum numbers of assets. If there are more than maxassets currently installed, the model stops as this is supposed to be not realistic	Integer > 0	Fixed: 200
Bankrupt	When finacial institutions ask a discount rate above bankrupt, the investors is assumed to go bankrupt	Floating point > 0	Fixed: 0,2
sizeasset	Size of an power generation asset (GW). Large scale power generation, coal gas is in 0,5 GW – 1 GW. For simplicity, in the model all assets have the same size: 1 GW	Integer > 0	Fixed: 1
Renewablesatinitialisation?	Boolean that allows renewable asset at initialisation	Boolean	Fixed: false
OPEXGbasis/OPEXCbasis	Basic OPEX costs for gas/coal assets	Floating point > 0	Fixed: 0
OPEXCrico/OPEXGrico	Increase of OPEX costs after the lifetime of the asset	Floating point > 0	Fixed: 0
Gasleadtime/coalleadtime	Time between investment decision and electricity production. Renewable lead time is assumed to be 0	Floating point > 0	Fixed : 0
Outputfile?	Boolean to determine if an output needs to	Boolean	Fixed: true

	be created during the modelrun		
Data-folder	Name of the file to which data will be written when outputfile? Is true.	Text	Fixed: file-name
Runthroughoutage?	Boolean to determine is the model allows for an outage to occur. If false, the model stops when an outage occurs.	Boolean	Fixed: true
Randomseedgenerator	Boolean to determine if a randomseed needs to be generator (true) by the model or manually given by the user (false).	Boolean	Fixed : true

4.1 Model narrative

Our model describes the time-evolution of the power system over years and decades. Within each year, the 'clock tick' of the model (the shortest timestep in an ABM) is a month. Every month electricity prices are calculated. The electricity price is determined by constant demand and variable supply in the merit order. The merit order is calculated with the short run marginal costs (SRMC) of all existing assets. The SRMC costs for fossil units are calculated on a day to day basis and are based on exogenous determined coal and gas prices, specific energy and efficiency of the different assets, the SRMC of green power generation are assumed to be zero, OPEX costs are neglected.

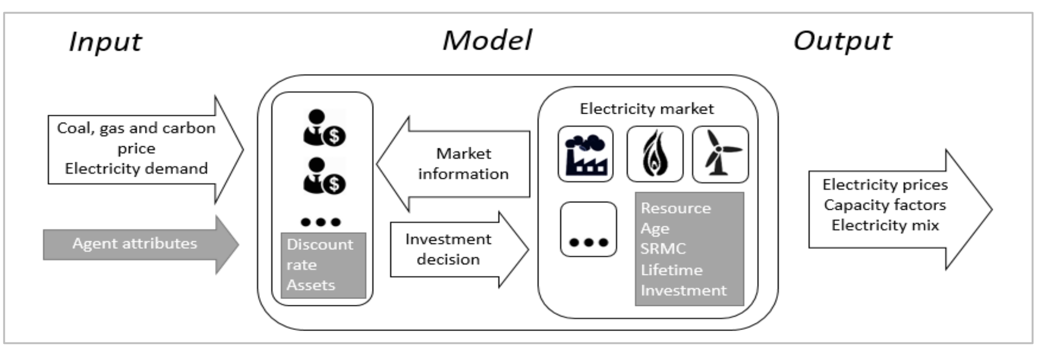

Figure 3. Model description. Investors invest in power generation units based on market information and their heterogeneous discount rate. These assets are part of the electricity market. Investors and assets are initialised with agent atributes (grey). Other inputs and outputs of the model are depicted (white).

After each year has passed, investors reflect on the market situation, adjust their anticipation of the future (future cost of technology, future market prices, volatility, etc.) and make investment decisions, taking into account their financial possibilities, reflected via their WACC in the discount rate they apply. Specifically, they do the following:

Investors calculate their profitability. Based on their monthly actual production and the monthly electricity price (including the scarcity rent), the investors calculate their income from each of the assets in their portfolio. From the income from electricity sales the profitability of the investors' asset portfolio is calculated. If an investor can show a solid profitability over the last year (above a determined threshold), his discount rate will decrease while if an investor has a poor performance (under a set determined threshold) his discount rate will increase. In the discount rate rises above a threshold, the investor goes bankrupt.

Investors evaluate new investment opportunities. They make NPV calculations based on their individual discount rates and the expectations about how these assets will perform in the future. The profits an investor can anticipate to make from a new asset, will depend on the place of that investment in the (future) merit order. Although coal- and gas-based electricity production is mature technology, new units will have a slightly higher efficiency than older units. Thus, a new unit, with a slightly higher efficiency, will be ahead of the currently most profitable unit (of the same type, gas or coal) in the merit order. And therefore, the expected profits of a new unit will correspond to the profit the existing unit made in the last year multiplied by the lifetime asset.

After evaluating all the options, investors decide to invest in an asset with the highest positive NPV (provided there is one). These assets are then placed in the system instantaneously and will generate power (and income) from that same year on. (That is, for the sake of simplicity we ignore investment lead times.)

New investors. New investors can enter the market when they see an investment opportunity with a positive NPV. New investors are initialised with an random discount rate within threshold values. Because only a limited amount of investors in the world are able to raise the capital needed to invest in these large scale electricity production units, only one new investor can enter the market each year.

Finally, assets may be taken out of operation and removed from the system:

Asset elimination. Assets 'die' when their lifetime is reached. This lifetime is fixed, and may be different for the different types of assets.

3. Design Concepts

1. Design concepts (Greeven, 2015)

Design concepts	Description
Basic principles	Which general concepts, theories, hypotheses, or modeling approaches are underlying the model's design? Explain the relationship between these basic principles, the complexity expanded in this model, and the purpose of the study. How were they taken into account? Are they used at the level of submodels (e.g., decisions on land use, or foraging theory), or is their scope the system level (e.g., intermediate disturbance hypotheses)? Will the model provide insights about the basic principles themselves, i.e., their scope, their usefulness in real-world scenarios, validation, or modification? Does the model use new, or previously developed, theory for agent traits from which system dynamics emerge?

Emergence	What key results or outputs of the model are modelled as emerging from the adaptive traits, or behaviours, of citizens? In other words, what model results are expected to vary in complex and perhaps unpredictable ways when particular characteristics of citizens or their environment change? Are there other results that are more tightly imposed by model rules and hence less dependent on what citizens do, and hence 'built in' rather than emergent results?
Adaptation	What adaptive traits do the model citizens have which directly or indirectly can improve their potential fitness, in response to changes in themselves or their environment? Do these traits explicitly seek to increase some measure of individual success regarding its objectives (e.g., "move to the cell providing fastest growth rate", where growth is assumed to be an indicator of success; see the next concept)? Or do they instead simply cause citizens to reproduce observed behaviours (e.g., "go uphill 70% of the times") that are implicitly assumed to indirectly convey success or fitness?
Objectives	If adaptive traits explicitly act to increase some measure of the individual's success at meeting some objective, what exactly is that objective and how is it measured? When citizens make decisions by ranking alternatives, what criteria do they use?
Learning	Many citizens or agents (but also organizations and institutions) change their adaptive traits over time as a consequence of their experience? If so, how?
Prediction	If an agent's adaptive traits or learning procedures are based on estimating future consequences of decisions, how do agents predict the future conditions (either environmental or internal) they will experience? If appropriate, what internal models are agents assumed to use to estimate future conditions or consequences of their decisions? What tacit or hidden predictions are implied in these
Sensing	What internal and environmental state variables are citizens assumed to sense or "know" and consider in their adaptive decisions? If agents sense each other through social networks, is the structure of the network imposed or emergent? Are the mechanisms by which agents obtain information modelled explicitly, or are citizens simply assumed to know these variables?
Interaction	What kinds of interactions among agents are assumed? Are there direct interactions in which citizens encounter and affect others, or are interactions indirect, e.g., via competition for a mediating resource? If the interactions involve communication, how are such communications represented?
Stochasticity	What processes are modelled by assuming they are random or partly random? Is stochasticity used, for example, to reproduce variability in processes for which it is unimportant to model the actual causes of the variability? Is it used to cause model events or behaviours to occur with a specified frequency?
Collectives	Do the citizens form or belong to aggregations that affect, and are affected by, the citizens? How are collectives represented? Is a particular collective an emergent property of the citizens, such as a flock of birds that assembles as a result of individual behaviours, or is the collective simply a definition by the modeller, such as the set of citizens with certain properties, defined as a separate kind of entity with its own state variables and traits?

Basic principles

In the model investors use Net Present Value (NPV) as the key metric in the evaluation of investment opportunities in power generation assets of different types. An NPV in excess of zero triggers investment action. The fact that investors have differing (*i.e.* heterogeneous) views about the future is expressed through a discount rate in the NPV calculations. These different discount rates are given to investors at initialisation. Additionally, at the initialisation, investors are given an existing portfolio of gas and coal assets. As time progresses, they can invest in new gas and coal assets, but also in renewables assets.

The electricity market has been modelled on the main properties of the real electricity market (electricity price depended on the merit-order).

Emergence

Model outcomes include the emerging electricity price and electricity mix, installed capacity, electricity price and price volatility. Days with outage, number of new investors, number of new assets, number of removed assets discount rate of investors, scarcity rent, capacity factors amongst others are all indicators for the development of the model

Adaptation

The adaptivity of investors is expressed in the model by making the discount rate of each individual investor dynamic. That is: each investor will see its discount rate increase or decrease over time, based on the profitability of its asset portfolio. In the course of the model runs, it thereby comes to reflect what is usually called the Weighed Average Cost of Capital (WACC), the most important metric of an investors financial performance track record. During the model run the discount rate an investor applies reflects therefore its expectations about the future, expressed by the discount rate at initialisation and its performance during the model run.

Objectives

Investors try to make money, following their basic investment logic. They are investing in the investment opportunity with the highest NPV. Asset do not have an objective, they just calculate their performance based on the electricity market where they are in.

Learning

Agents learn in the sense that their discount rate is adapted to their performance, and their expectation is based on the performance of the best performing assets in last years' electricity market.

Prediction

Investors make predictions about the future performance of their potential new investment based on the performance of the different assets in the last year.

Sensing

Investors or assets do not sense each other.

Interaction

Interaction between the agents runs all via the electricity market so there is no direct interaction.

Stochasticity

Assets and investors are regularly asked to perform a certain procedure in random order. Discount rates are given random to investors in a pre-defined range. Age of assets at initialisation is given at random in a pre-defined range.

Collectives

There are no collectives represented in the model.

Observation

Model outcomes include the emerging electricity price and electricity mix, installed capacity, electricity price and price volatility. Days with outage, number of new investors, number of new assets, number of removed assets discount rate of investors, scarcity rent, capacity factors amongst others are all indicators for the development of the model.

4. Details

4.1. Initialisation

How the model is initialised is discussed extensively in the process and scheduling chapter.

4.2. Input data

The model does not use input data to represent time-varying processes.

4.3. Submodels

The model has been exhaustively described in section 1 and 2 of this protocol.

5. Bibliography

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