DECENT: An Ontology for Decentralized Governance in the Renewable Energy Sector

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***Abstract*—The energy sector is a complex ecosystem in which many actors participate. In the EU, the energy sector is changing significantly as part of the energy transition. One important change is decentralization of energy, for example the bilateral trade of energy between households generating energy by solar panels and consuming energy. A key question is how to design the decentralized governance structure of such an ecosystem. We propose the DECENT *(decentralized)* ontology, which results from an extensive literature study in the field of decentralized governance in the energy sector, which allows to describe governance in ecosystems in a structured way. Its intended user-base are business developers and ecosystem designers. The DECENT ontology provides the terminology to represent and analyze important governance constructs for these stakeholders. We demonstrate the practical use of the ontology by means of a case study about peer-to-peer energy trading.**

***Index Terms*—Ontology, Decentralization, Renewable Energy, Governance, Ecosystem**

I. Introduction

Decentralized governance is a concept that is emerging as a result of increasing popularity of peer-to-peer (P2P) and blockchain technology. Take for example the Bitcoin ecosystem, in which the trusted third party (TTP) is completely eliminated and instead actors exchange money with each other by means of *computational* trust. We define an ecosystem as “a collection of companies that work cooperatively and competitively to satisfy customer needs” [1]. Here the need is to transfer money from one actor to another actor. Although Bitcoin (and related platforms such as Ethereum) are completely decentralized in their operations, their governance is clearly not [2]. In practice only a limited number of actors influence how Bitcoin and Ethereum protocols evolve. There is some governance process, called Bitcoin / Ethereum Improvement Proposals (B/EIPs) but this is very informal and open for interpretation. The central claim of blockchain technology, namely reduction, or even removal, of the middleman and/or centralized decision taking authority, also implies that its corresponding governance model should be decentralized, e.g. not done anymore by a centralized party (or a small group), but by a representative governing ecosystem of parties in a collaborative role. We define governance in decentralized ecosystems as …“the set of rules a system has to obey, and which are set by another system” [3].

Bitcoin and Ethereum are both examples of *non-permissioned* eco-systems, and are fully decentralized, implying that everyone can join and exit the ecosystem. In such an ecosystem, to be truly decentralized, it would be reasonable to expect that each participant has a role in the governing ecosystem, which is currently not the case. Another class of blockchain systems is the *permissioned* system, which requires an entity (e.g. a committee) that decides which actors may join and leave the ecosystem. Clearly, such a decision process for entering and leaving the ecosystem is strongly related to governance, which again should be decentralized to be compatible with the most important promise of blockchain, namely decentralisation.

The definition of governance that we have provided illustrates the concept on a fairly high abstraction level. It is useful to explain to others what we mean by governance, but is not very convenient in computational terms, or as an aid in designing a governance system for a particular ecosystem. Therefore, in this paper, we propose the DECENT ontology for the notion of decentralized governance, solid grounded in literature. DECENT stems from the word *decentralized*. In this paper, we focus on governance in the energy sector, demonstrating that our ontology is also useful in other sectors will be topic of further research.

For our DECENT ontology, we foresee two uses. First, the ontology can be used as a vocabulary to express governance decisions regarding ecosystem design. Second, the ontology can be the foundation for computational governance. Blockchain platforms, such as Tezos [2], [4], recognize the importance of decentralized governance, and try to support it by using blockchain technology. Our emphasises with this research is developing an ontology as an aid in decentralized governance design. This paper is structured as follows. Section II discusses related work regarding decentralized ontologies. Section III elaborates the research methodology. Section IV presents DECENT ontology, its requirements, knowledge elicitation, and conceptualization of the governance concepts. Section V, the case of decentralized energy trading is presented and DECENT Ontology is applied to the case. Section VI reflects and discusses DECENT ontology. Section VII concludes the paper.

II. Related work

In [5], various ontologies are discussed related to blockchain, and hence decentralized systems. Two approaches are presented. First, the notion of *Decentralized Autonomous Organization* (DAO) is of relevance for governance ontologies, and is further discussed in [6]. DAO "is an organization that is run through rules encoded as computer programs called "smart contracts" [7]. The relation with the DECENT ontology is that *rules* in DECENT can be implemented as DAO smart contracts. The (ontological) notion of *smart contract* (eSourcing/eSML) is discussed in [8]. It distinguishes the concept of *party*, which we also have in DECENT, the *business context* and *legal context*, the latter in DECENT called *legislation*, consisting of *rule*s, the *exchanged value* and *provisions* which are not present in DECENT but can be considered as part of the *rule*, *process* which is called *mechanism* in DECENT, and *monitorability*, which in DECENT is captured by the relation between *mechanism* and *objective*. However, the notion of decentralized *decision making* in DECENT is not considered in this work, and also not the notion of *group* which we consider important for decentralized constellations. Also, the concept of *incentive* is lacking, [9] adds the notion of *conflicts* and resolution of these. Conflicts are not part of DECENT yet, but the potential outcome, a *penalty* is.

Second, the Toronto TOVE Organization Ontology is introduced [10]. TOVE has some concepts we also distinguish in DECENT. The *role* concept in conjunction with the *authority* and *empowerment* concepts come close to our interpretation of *role*, although TOVE's notion of *role* has a more operational interpretation than ours. TOVE has the idea of *goal* which is defined as a *state* (satisfying the *goal*) by means of an *activity*. In DECENT, we also have the notion of *goal*, but with a stronger focus of actors to commit resources to achieving the *goal*. This allows a better differentiation of the *goal* and *activity* constructs, which leads often to confusion. Furthermore, TOVE has various flavours of *organization* (including profit, non-for profit, and commercial) that closely resemble our notion of *actor*. TOVE's classification of *organization* is useful as detailing taxonomy for our *actor* concept. In TOVE, there is the concept of *policy*, which is defined as *constraints* on a process performed. IN DECENT, a *policy* is defined as 'a plan of action', thereby taking a more declarative point-of-view on *what* should be done to implement *legislation* and *regulation*. This allows to abstract away from *how* policies are actually implemented. Finally, TOVE has a focus on processes (*action*, *activity* and *process*), which in DECENT is called *mechanism*. We have not further detailed the notion of *mechanism* as there sufficient process-oriented approaches available for doing so. TOVE is missing DECENT concepts such as *legislation* and (self)*regulation*, and their decomposition into a set of *rule*s, which are essential constructs for decentralized governance.

Finally, we have also evaluated whether the e^3*value* ontology [11] is suitable to represent the governance construct [3], specifically for the peer-to-peer energy case in this paper (see Sec. V). To summarize, in an e^3*value* model decisions regarding the revenue model can be represented, which are related to governance, similar to investments and cost-sharing. Roles and responsibilities can be partly represented by value activities; risk and expectations by assessing what-if scenarios. Decision making itself can not easily be seen; however the distribution of power can be seen by quantifying and analyzing the e^3*value* model.

III. Research approach

For this paper, we identify the following research questions:

RQ 1 What is an ontological well founded conceptualization of the notion of "decentralized governance"?

RQ 2 Is the resulting ontology instrumental in structuring and presenting governance decisions in the realm of decentralization of the energy ecoystem?

To construct the DECENT ontology (RQ 1), we use the following approach, amongst other inspired by [12]. We first state the requirements for the DECENT ontology (the specification phase), then we elicit the well-accepted knowledge concerning decentralized governance by carrying out a Systematic Literature Study which is the knowledge acquisition phase, followed by conceptualization using UML class modelling. Regarding RQ 2, we use the DECENT ontology to discuss governance choices made for a case in decentralized renewable energy trading. We recognize that evaluation of the DECENT ontology requires future research, including application in other domains, and use of the ontology by domain experts. The latter will be topic of further research.

IV. The DECENT ontology

A. Requirements

Requirements regarding an ontology can be expressed in terms of the *subject area*, *purpose*, *scope*, and the *intended user base* [12]. Regarding the *subject area*, DECENT ontology is about decentralized governance. We have defined governance as "the set of rules a system has to obey, and which are set by another system" [3]. As governance is a very broad topic, we narrow the subject area down to (1) *decentralized governance* in (2) *ecosystems*. An ecosystem is "a collection of companies that work cooperatively and competitively to satisfy customer needs" [1]. The notion of "decentralized" implies that governance is exercised by more than one party, e.g. a subset of the parties in the ecosystem under consideration, and often results in a multi-party process (e.g. voting) to take governance decisions. This leads to our definition of decentralized ecosystem governance: set of rules an ecosystem has to obey, and which are set by (a subset of) parties in that ecosystem.

The *purpose* of the DECENT ontology is twofold. For now, it should serve as an instrument to guide and express governance decisions regarding an ecosystem. In a later stage of the research, it should also provide the foundation for *computational* decentralized governance; which e.g. can be used on-chain governance of blockchain platforms such as Tezos [2], [4]. Currently, DECENT ontology can be best characterized as a *reference* ontology, which is an ontology designed to describe a certain domain [13], [14], in our case decentralized governance.

We restrict the *scope* of DECENT ontology to the application domain of *renewable energy ecosystems* for now. Renewable energy ecosystems refer to ecosystems that produce, distribute and consume energy such as photo-voltaic cells, hydro power, and wind power, e.g. energy without the use of fossil fuel, and often with the goal of CO_2 emission reduction. Although the focus is on decentralized renewable energy ecosystems, we keep, while constructing the ontology, in mind that the ontology should also applicable to other industries. Future research will also include other sectors, such as the FinTech, entertainment sector, and ICT for development (ICT4D).

Regarding the *intended user base*, we concentrate on the first purpose of the DECENT ontology, namely representing governance decisions by stakeholders who have to design governance for a particular ecosystem. These stakeholders can be persons representing the parties in the ecosystem and their consultants. We assume however knowledge about conceptualization (e.g. obtained by a suitable training). The second purpose, supporting decentralized computational governance, has as its 'users' blockchain platforms that can use the ontology as a basis for computational support. We recognize that the proposed DECENT ontology needs to be extended to offer computation support. However, for now, we restrict ourselves to support governance design decisions.

B. Knowledge elicitation

To ensure ontological commitment, e.g. a shared understanding, we execute an extensive literature search on the concept of decentralized governance in ecosystems, as defined by our *purpose* requirement. Moreover, we restrict our literature search to the energy domain only. In subsequent research, we extend to other domains (see the *scope* requirement).

For the extensive systematic literature review, we use the following topic descriptors: "Renewable Energy Governance", "Meta-Governance Ecosystem", "Governance Ecosystem", "Governed Eco-system", "Governance Definition", "Decentralized Energy Ecosystem," and "Peer-to-Peer Energy Trading". These topics are partly domain specific (e.g. renewable energy), and partly based on earlier work about the *governance paradigm* [15]. We analyzed over 150 peer reviewed papers and over 80 papers were selected based on specific topics they discuss.

C. Conceptualization

We only include papers, obtained during the knowledge elicitation phase, that discuss (1) governance (due to the topic of interest), and (2) the energy domain (to restrict the scope since the notion of governance is overwhelming). Then, the selected papers, are summarized based on the abstract, keywords, definitions of governance and decentralization (and motivation), and governance-related concepts distinguished.

Subsequently, we classify governance concepts in the papers using the *governance paradigm*. In earlier work [15] we developed this paradigm to distinguish the various levels of abstraction where governance can occur. To summarize, we distinguish the (being) *governed* system, the (exercising) *governance* system, and the *meta-governance* system (governing the governance system). All these systems provide monitoring data (e.g. about being compliant) to the hierarchical higher system (doing the governance), which in turn provides rules to lower (governed) system. We have found that the same terminology in governance-related papers re-occurs at these different abstraction levels; hence we use the three abstractions to reduce and unify terminology found in the publications. This results in a shortlist of governance concepts.

As our goal is to design a tractable, lightweight ontology with a minimum number of concepts, we reduce the shortlist even further by focusing on nouns only (or concepts that can easily be formulated as nouns), and by clustering closely related concepts. By doing so, we are able to minimize the number of ontology concepts significantly. To understand the relations between the concepts a cross reference analysis between the concepts is performed. As a final step, the ontology is created (using informal UML).

We consider the DECENT ontology as a semi-formal, explicit specification of a shared conceptualization of a domain, namely decentralized governance in ecosystems (see e.g. [16]–[18]). The idea of explicit specification goes via a semi-formal specification, in our case a UML class diagram. More formal approaches such as the Unified Foundational Ontology (UFO) [19] can also be used, but for our purpose, UML class diagrams are sufficient. We use a more tractable form of the UML class diagram notation, consisting of classes, properties, associations, generalizations (is-a), and cardinality constraints. The level of conceptualization of the DECENT ontology should correspond to our *purpose* requirement (assisting governance decisions in ecosystems), as well as to the *intended user base*: stakeholders of the parties in ecosystems as well as their consultants. This calls for a lightweight, and tractable ontology. In contrast to the many machine processable ontologies, the DECENT ontology has a limited number of concepts and relations, such that it can easily be explained to practitioners. A minimized ontology, cf. Occam's razor, is an important feature of the the DECENT ontology (see Fig. 1). We discuss the ontology below.

Concept: **Governance construct**

Definition: All DECENT ontology concepts, except *party*, *group*, *actor* and *role* are generalized into the notion of *governance construct*.
Explanation: The abstraction *governance constructs* is needed because a *party*, via its *role* can be related, in different ways, to each of the various governance constructs.
Properties: n.a.
Relations: A governance construct is the generalization of *decision making*, *rule*, *rule set*, *mechanism*, *policy*, *goal*, *objective*, and *incentive*. To avoid cluttering of the diagram, these generalization relations are not presented graphically.
Example: n.a.

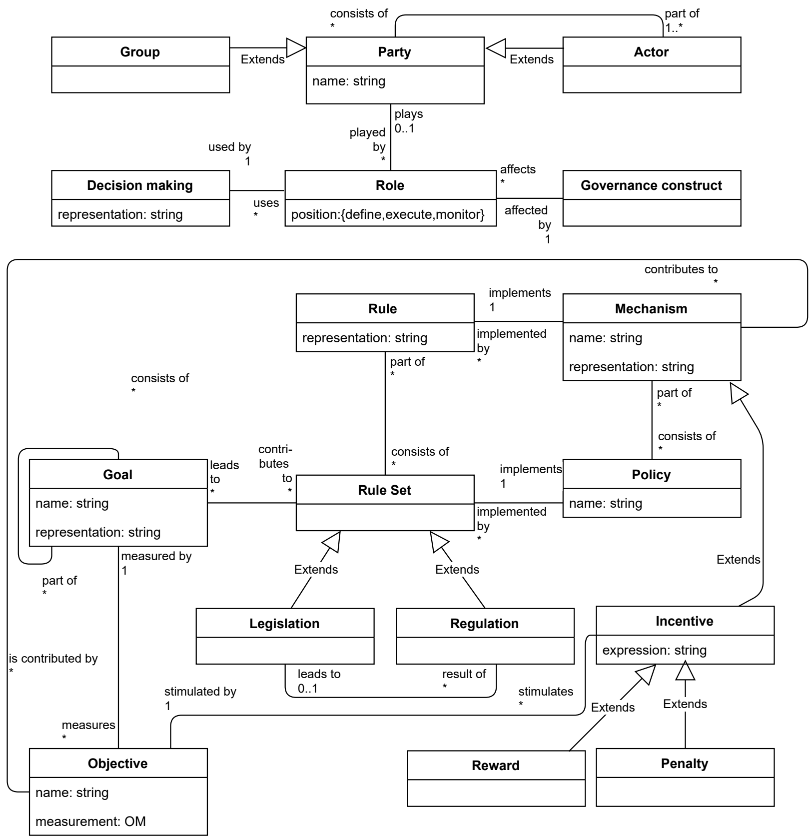

Fig. 1. The DECENT ontology

References: n.a.

Concept: **Party**

Definition: An party is any entity that can play a *role* regarding a *governance construct*.
Explanation: A party is the abstraction of an *actor* or a *group*. Both can play several *role*s as one unit of control regarding *decision making* in relation to a governance construct.
Properties: A party has a *name* that uniquely identifies the party. This can be a company name, the name of a private person, but can also refer to a particular kind of actor, e.g. government.
Relations: A party *plays* one or more governance *role*s. An party is *part-of* a *group*.
Example: See *actor* and *group*.
References: n.a.

Concept: **Role**

Definition: A role is the position that a *party* has to a governance construct.
Explanation: Sowa [20] defines roles as accidental or temporal relations to individuals (called 'actors' by us). According to [21], roles depend on relationships. We focus on the notion of the *position* of the party in relation to the governance construct.
Properties: A role has a *position*, which is a selection of *set* (e.g. determine a rule), *execute* (e.g. be compliant to a rule), and *monitor* (collect information to check compliance to a rule).
Relations: A role is *played-by* a *party*. A *governance construct* is *affected-by* one or more roles. A role *uses decision making* to reach agreement. The choice for a particular decision making method depends on the role a particular *party* has in relation to the *governance construct* at hand.
Example: The EU *set*s the objective of CO_2 emission reduction with x Mton/year, The Netherlands executes (being compliant with) CO_2 emission reduction with y Mton/year, the EU *monitors* compliance of The Netherlands with the set CO_2 emission reduction goal.
References: [20], [21]

Concept: **Actor**

Definition: An actor is an entity that is responsible for its survival and well-being.
Explanation: The actor is perceived by itself and its environment as independent. This definition is imported from the e^3*value* ontology [11] and focuses on the capacity of the actor to take its own legal and economic decisions. We argue this capacity is the basis underlying any governance activity. A taxonomy of actors may be useful, e.g. the government, companies, branch organisations, non-for-profit organisations, persons, in general actors who determine the kind of gover-

nance, actors who have to comply to the stated governance, and actors who monitor compliance with governance (see the *role* concept below).
Properties: n.a.
Relations: An actor *is-a party*.
Example: The Netherlands (government), The EU (meta-government), PV cell owner (household).
References: [11]

Concept: **Group**

Definition: A group is a collection of *parties* that share one or more characteristics.
Explanation: Sometimes, a group rather than a single *party* plays a governance *role*. Examples include a branch organization, or even a society. Grouping can be based on characteristics, e.g. the same *goal*.
Properties: n.a.
Relations: A group *is-a party*. A group *plays* one or more governance *role*s. A group *consists-of* one or more *parties*.
Example: The EU citizens.
References: n.a.

Concept: **Decision making**

Definition: Decision making refers to a collection of different methods used by a *party* to take a decision, or to reach agreement in case of a *group*.
Explanation: In decentralized governance, understanding the path how decisions are made is important. In case of a single *actor*, decision making can be rationalized using a set of prioritized criteria, in case of a *group*, the *actors* in the group should come to an agreement regarding a particular topic. This can be done in various ways, e.g. hierarchical (one *actor* is appointed as the decision maker), various ways of voting (delegation, referendum), etc. Note: since 'decision making' *is-a governance construct*, a *party* can have a particular *role* in relation to the particular decision making instance. If for example the *role* is 'set', this states that the *party* decides about the decision making method to be used, but not necessarily that the actor *makes* the decision.
Properties: Decision making has a *representation*, e.g. by using an ontology on decision making, such as [22]–[24].
Relations: Decision making is *used-by* a *role*.
Example: Hierarchical decision making, direct voting, and delegated voting are decision-making examples.
References: [22]–[26].

Concept: **Rule**

Definition: A rule is a proceeding that is required, permitted or prohibited.
Explanation: Holistic view of rules execution that is required to achieve a desired outcome.
Properties: An rule has an *representation*, formal or informal that captures the rule. Rules can expressed by means of already existing techniques such as LegalRuleML [27], or more recently, Symboleo [28].
Relations: A rule can be *part-of* (multiple) *ruleset*(s). Rules can be *implemented-by* means of *mechanisms*.
Example: Maximum kWh that can be traded per day in order to prevent overload of the energy infrastructure
References: [29], [29]–[37]

Concept: **Rule Set**

Definition: A rule set is a coherent set of *rule*s.
Explanation: *Goal*s and *Policy* have a cohesive, related, set of rules that contribute to satisfying the goal and/or have an implementation in terms of a policy. Usually, a number of related rules are needed to reach a goal.
Properties: n.a.
Relations: A rule set *contributes-to* satisfying a *goal*. A rule set is *implemented-by* a *policy*.
Example: See legislation and regulation.
References: n.a.

Concept: **Legislation**

Definition: Legislation is-a *rule set* and set (*role*) by a government.
Explanation: Legislation (a.k.a. as the law) has a formal character. Note that here are a few *roles* relevant; the government *set*s legislation and compliance to regulation is *monitored* by the government too. Actors in a society have to comply (*execute*) with the legislation. In terms of *meta-governance*, in a democracy individuals *monitor* the government, e.g. in terms of reaching *set objective*s.
Properties: n.a.
Relations: Legislation may *lead-to regulation*.
Example: Laws that determine which renewable energy sources can be utilized
References: [30], [38]–[41]

Concept: **Regulation**

Definition: Regulation is-a *rule set* and can be set (*role*) by any (group of) actor(s).
Explanation: Regulation is similar to *legislation* but where the government has the monopoly to set legislation, regulation can be set by one. As such, it has not a formal legal character in the sense of laws. Regulation can be set by a society of actors, a branch organization, or even can be self-imposed by one or more actors ('self-regulation').
Properties: n.a.
Relations: Regulation may be the *result-of* (often a further detailing) *regulation* but this is not required.
Example: Regulation that allows and enables peer-to-peer energy trading
References: [33], [36]–[38], [42], [43]

Concept: **Goal**

Definition: A goal is desire to fulfill, for which an *actor* has committed resources for.
Explanation: The idea that an actor has to commit resources in order to achieve a goal is important; there is no free ride. Goals can be set by a single actor, by a group (e.g. a community),

or even a society (e.g. the Sustainable Development Goals (SDGs) of the United Nations.
Properties: A goal *name* that uniquely identifies the goal, and a *representation*.
Relations: Goals can be part of a goal hierarchy using the *consists-of* relationship. Goals lower in the hierarchy (partly) contribute to satisfaction of the goal higher in the hierarchy. Goals may be have constraints (not represented in the ontology), indicating that multiple goals must be satisfied (AND), a selection of goals must be satisfied (OR), or are exclusive (XOR), see [44] for an example). Satisfaction of a goal is *realized-by* one or more *objective*s.
Example: Achieve reduced CO_2 emissions.
References: [34], [38], [45], [46], [46], [47]

Concept: **Objective**

Definition: Objectives measures (party) satisfaction of a goal.
Explanation: Goals are stated qualitatively (CO_2 reduction), objectives allow to measure achievement of the goal (100 Mton CO_2 reduction in 2030). In some cases, multiple objectives need to be achieved for goal satisfaction. We do not include an ontology to represents the actual *measure*, but instead rely on existing ontologies, e.g. the ontology units of measure (OM) [48], or [49] for a survey.
Properties: A goal *name* that uniquely identifies the objective, and a representation of the *measurement* of the objective, e.g. using OM.
Relations: An objective(s) *realizes* a *goal*. Reaching an objective can be *stimulated-by incentive*s or *penalty*s.
Example: Enhancing the energy efficiency of 1,5 million homes and a reduction of 1 Megaton CO_2 for utility buildings.
References: [34], [46], [50]–[52]

Concept: **Policy**

Definition: A policy is a plan for action, consisting of coherent set of *mechanisms*, to implement a particular *rule set*, being either a *legislation* or a *regulation*.
Explanation: To achieve a *goal* through a (complex) set of *rule*s, often a set of *mechanism*s are needed, that potentially reinforce each other to comply to the *rule set* and ultimately *goal* satisfaction.
Properties: An policy has a *name* that uniquely identifies the policy.
Relations: A policy *implements* a *rule set*. A policy *consists-of mechanism*s, which applied in combination, comply to the rule set.
Example: Collective set and describes how to reduce CO_2 emissions *goal* and which actions are required.
References: [30], [42], [43], [50], [53]–[56]

Concept: **Mechanism**

Definition: A mechanism contributes to (partial) satisfaction of a *goal* (via its associated *rule*, part of a *rule set* in terms of reaching an *objective*.
Explanation: Typically, a mechanism is process-oriented. Hence, process modelling techniques such as the Business Process Modelling Notation (BPMN) [57] can be used to represent a mechanism. Note that BPMN has also a notion of *actor* by means of resource pools.
Properties: A mechanism has a *name* that uniquely identifies the mechanism. A mechanism has an *representation*, e.g. a BMPN model
Relations: A mechanism *implements* a *rule*. A mechanism is *part-of* a *policy*. A mechanism *contributes-to* reaching an *objective*. A mechanism is the generalization of *incentive*.
Example: Clean development *mechanism* to reduce emissions by buying greenhouse gas reduction units from mainly developing countries.
References: [35], [58], [59]

Concept: **Incentive**

Definition: An incentive is a stimulation to achieve *objectives* and indirectly adhere to *rule*s.
Explanation: Actors can be motivated to strive for reaching an *objective* and hence *goal* satisfaction. This motivation be positively by a *reward* or negatively by a *penalty*.
Properties: An incentive has an *expression* stating the reward of penalty.
Relations: An incentive is a *mechanism*, and as such can *implementing* a *rule.* An incentive is the generalization of *penalty* and *reward*. An incentive *stimulates* to reach an *objective*.
Example: See reward and penalty.
References: n.a.

Concept: **Reward**

Definition: A reward is a motivation to achieve *objectives* and indirectly adhere to *rule*s.
Explanation: A reward is an example of the carrot and stick; desired behaviour results in a reward.
Properties: n.a.
Relations: A reward *is-a incentive*.
Example: Energy tax system with incentives for energy efficiency and CO_2 reduction.
References: [38], [42], [51], [60]–[63]

Concept: **Penalty**

Definition: A penalty is a punishment if *objectives* are not met and *rule*s are not adhered to.
Explanation: A penalty is an example of the carrot and stick; unwanted behaviour results in a penalty.
Properties: n.a.
Relations: A penalty *is-a incentive*.
Example: EU members who fail to meet their targets face a penalty in the form of a periodic penalty payments.
References: [31], [51], [58], [62], [64], [65]

V. Case: Decentralized energy trading

We have been involved in the design of a disruptive decentralized ecosystem regarding the trade of energy. This ecosystem enables peer-to-peer trading. In Sec. V-A, we summarize the case. Note that this description was written after closure of the project; at the beginning of the project we were not able to express the case this way. To test the descriptive validity of the DECENT ontology, we describe in Sec. V-B the same case by using the DECENT ontology (see Sec. IV).

A. Case description

The global climate agreement states that by 2030, 70% of global energy consumption should come from renewable energy sources. This is often referred to as the 'global energy transition'. Part of this transition is that households contribute to renewable energy generation, often by employing Photo-Voltaic (PV) cells on their roof. In The Netherlands, the current regulation is beneficial for households, as they are allowed to subtract the generated energy by their PV cells from the energy they consumed *on a yearly basis*. This *regulation* is called 'the netting agreement', and ensures that households receive the same amount of money for the energy generated as they have to pay for energy consumed, provided that the total amount of energy generated is equal or smaller than the total amount of energy consumed. The caveat is in the fact that during summer households generate more energy than they can consume, and during winter they consume more than they produce. The netting agreement ignores this timing effect and assumes that the surplus of energy generated during the summer can be 'stored' somehow for consumption during the winter. Storing electrical energy is very expensive and not efficient. Therefore, during summer, large scale generators are switched off (so that the surplus of PV cell energy can be consumed) and during winter the same generators are switched on again (so that shortage of PV cell energy can be compensated for). Switching off large scale generators is costly, because when switched off, these generators do not produce an income. As the netting agreement does not have a fee for switching off these generators, large energy suppliers are rightfully complaining that they pay the bill for the 'netting agreement'.

Consequently, the Dutch government plans to discontinue the netting agreement, and instead installs a regulation that allows for different tariffs for electricity consumption and production, and moreover do not allow netting anymore; e.g. a fee is paid for generated energy and charged for consumed energy directly, without yearly netting. Obviously, the selling price for generated energy by larger suppliers is (much higher) that the price these same suppliers pay to buy household-PV cell generated electricity.

Due to other upcoming *regulation*, it will be possible for prosuming household to *sell* electricity directly, e.g. with other households, for a substantial *higher* price (e,g 0.10 Euro/KWh) than households would receive from traditional large suppliers (e.g. 0.06 Euro/KWh). However, prosumers and/or consumers who *buy* electricity from peer prosumers for a *lower* price (e.g. 0.10 Euro/KWh) than from the large suppliers (e.g. 0.20 Euro/KWh). Hence the ecosystem is beneficial for both the prosumers and consumers. This is often referred to as *peer-to-peer* trading. We have been involved in the ecosystem design of such a peer-to-peer trading system, which is facilitated by blockchain technology. Note that many peer-to-peer trading systems still use a centralized model, namely an entity that buys energy from households, and sells energy to households. The decentralized ecosystem for energy trading, in terms of an e^3*value* model, is described in Fig. 2. There are two types of households: (1) prosumers who produce *and* consume energy, and (2) consumers who only consume energy. A prosumer first 'sells' generated energy to itself, and once it has a surplus, it sells it to peer(s), being either another prosumer or consumer. If then still energy is left, the remaining energy is sold to the Local Energy Community (LEC), which is a cooperation of all prosumers and consumers in a particular region. The LEC sells a surplus of energy to traditonal (large) energy suppliers. When all prosumers and consumers are united in the LEC, it can negotiate a higher price for the energy than an individual prosumer would be able to do. What happens with the energy once it is sold the supplier is not modelled, since this cf. the old ecosystem. If there is a shortage of energy, e.g. a prosumer does not generate enough energy for its own or peers needs, the opposite happens: energy is bought by the LEC from an electricity supplier and re-sold to the prosumer and/or consumer. Note that the LEC comes only into play for trading if peers have a surplus or shortage of energy. A special characteristic of the physical electricity network is that *at any moment* the total amount of electricity consumed should be the same as the total amount of electricity produced. This balance is managed by the Transmission System Operator (TSO), usually one per country, To ensure balance, there are Balance Responsible Parties (BRPs) who forecast their energy consumption/production every 15 minutes. The TSO uses these forecasts to calculate if balance is maintained the next 15 minutes. In case of imbalance, generators and/or loads will be directed to switch on or off. Obviously, forecasts may differ from actual realization. If a party causes imbalance in the electricity network by a wrong forecast, a penalty has to be paid to the TSO. In Fig. 2, the prosumer is considered as a BRP, who needs to forecast the planned energy to be generated to the LEC. The LEC aggregates these forecasts, and reports the result to the TSO. In case a prosumer causes imbalance (e.g. not complies to its own forecast), a penalty has to be paid to the LEC. The LEC aggregates the received penalties, and pays the penalty to the Transmission System Operator (TSO), who uses the penalty to buy/sell emergency energy to ensure that the electricity grid is in balance all times (not modelled).

B. Case expressed using the DECENT ontology

We demonstrate the descriptive capacity of the DECENT ontology by describing the governance concepts in Sec. V-A. Use of DECENT ontology concepts and relationship are in *italic*. The European Union (EU) (an instance of *actor*), who *plays* a *defining role*, *affects* the *goal* in becoming the first climate-resilient and neutral society by 2050. Satisfaction of this *goal*, is *realized-by* the *objective* to reduce the carbon emissions with 50% in 2030 (*measure*), and to be climate neutral in 2050 (*measure*). The arrangement that should accomplish the *goal* is the 'Green Deal', which *leads-to*

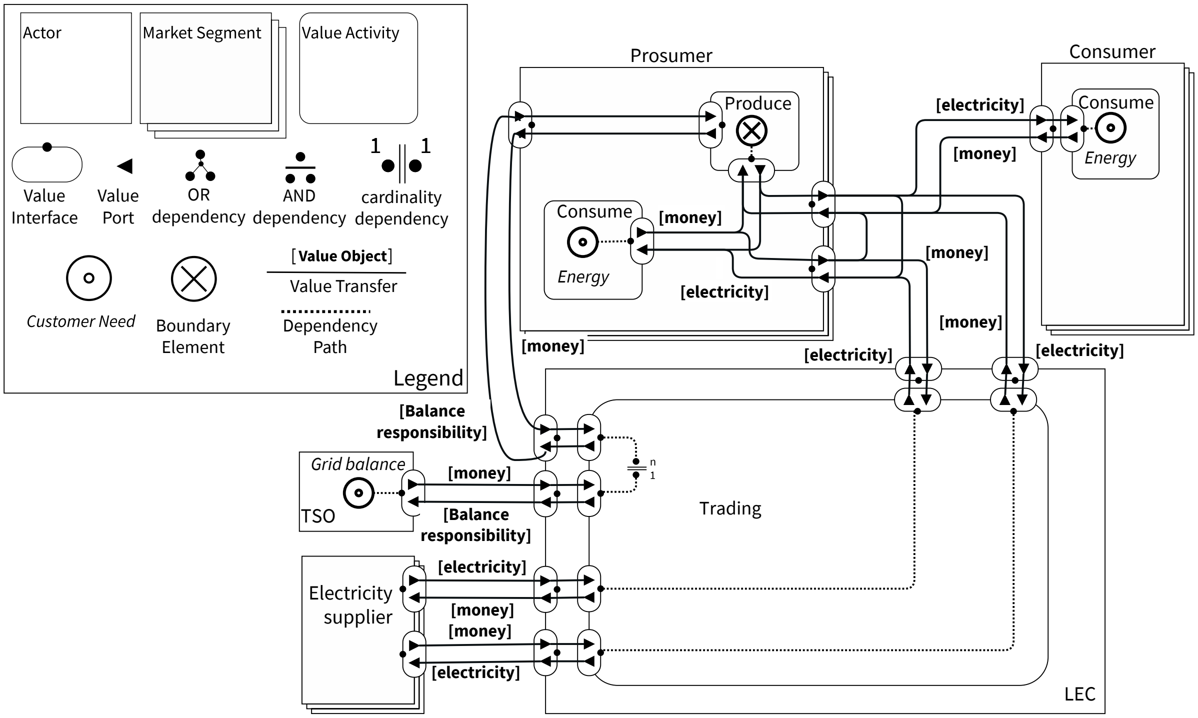

Fig. 2. *e^3value* Model of Peer-to-Peer Energy Trading

legislation referred to as the EU climate law. This *legislation consists-of* a series of *rules*. One example of a *rule* is that "Union-wide emissions and removals of greenhouse gases regulated in Union law shall be balanced at its latest by 2050, thus reducing emissions to net zero by that date" [66]. The formulation of the rule comes very close to the formulation of the stated *objective*. Apparently, the EU has chosen to state the *objective* as a *rule* of law too. The EU climate *legislation* is *implemented-by* various *policies*, e.g. the "creation of markets for climate-neutral, circular economy products" [67]. The *policy consists-of* several *mechanisms* including "supporting cost competitiveness of climate neutral and circular economy solutions", "public procurement and standards supporting market creation", and "empowering customers and consumers" [67]. The EU climate law also comes with various *penalties*: for example car manufacturers have to comply with a specific emission target *objective*, which is *stimulated-by* a *penalty* of "95 Euro per g/km of target exceedance" [68]. This *penalty* also *is-a mechanism* and hence partly *implements* a rule.

The member states of the EU have implemented the Green Deal, first by ratifying the EU climate agreement in national laws. Representation in terms of the DECENT ontology follows the schema of the EU, with specific local arrangements. Due to lack of space, we do not elaborate on national *legislation* further. However, we point out that EU member states are democracies and hence there is a *group* that *consists-of parties*, being people eligible to vote. This *group* elects on a periodical basis the government *using* a *decision making* procedure called 'voting'. For the peer-to-peer trade of energy there is a *group consisting-of actors*, both prosumers and consumers, who together form the LEC. This *group* plays a *defining* and *monitoring role* in terms of (self)*regulation*, *rules*, etc. The *group uses* a *decision making* procedure, e.g. based on voting. Consequently, the LEC should not be considered as a centralized party, but as a cooperation of *actors part-of* a *group*. The *goal* setting of CO_2 emission reduction as *defined-by* the EU, reaches through national *legislation* prosumers and consumers. Prosumers have *executing role*s, namely "produce" and "consume", the latter is also the *role executed-by* the consumer. A *goal* is also to maintain *balance* in the electricity network, which is *defined* and *monitored* by the TSO. Satisfaction of the balance *goal* is *measured-by* the *objective* to have only 1% deviation between forecast and realization. The TSO has a *monitoring role* with respect to this *objective*. The *penalty*, and therefore also the *incentive* and *mechanism* is a fee to be paid, which depends on the difference between forecast and realization.

VI. Discussion

Does the description with support of the DECENT ontology represents governance in the case at hand adequately (*descriptive validity*)? We argue that a certain abstraction level, the ontology can represent the EU Green Deal, but also a concrete case such as peer-to-peer trading in conjunction with an *e^3value* model. The *e^3value* model describes the governed ecosystem, the DECENT ontology represents how this ecosystem can be governed. Furthermore, there is another relationship between the *e^3value* model and the representation of the case using the DECENT ontology. *Incentives*, a construct of the DECENT ontology, are also visible in the e^3*value* model, because incentives, either positively (*rewards*) or negatively *negatively* reflect economic value. We expect that the representation is useful as a structuring mechanism for skilled consultants to design governance systems as the DECENT ontology is lightweight, but validating this expectation requires further research. Also, the ontology provides hooks for extending/detailing the ontology to increase its usability for a more detailed representation of the governance construct. Specifically *decision making*, *goal* (goal hierarchies, *i**, *rule set* (LegalRuleML, Symboleo) and *mechanism* (BPMN) can benefit from more detailed existing modeling approaches and ontologies.

Since decentralized governance is a difficult construct to understand, we have deliberately chosen to focus on governance within a specific domain, namely renewable energy ecosystems. This affects external validity of the ontology (e.g. usability of the ontology in other domains), but is a required step to arrive at a meaningful ontology. A topic of further research is to use the DECENT ontology in other domains to test its re-usability. We are optimistic about the useful application of the DECENT ontology since the ontology does not contain specific concepts for the energy domain at all. However, it might be possible that other domains have different (general) interpretations of the notions of 'governance'.

Revisiting the research questions, with respect to RQ 1, "What is an ontological well founded conceptualization of the notion of "decentralized governance?", we have presented the DECENT ontology, which is firmly grounded in the literature by means of a SLR. Since the SLR was limited to the meaning of 'governance' in the energy domain, it should be extended to the other domains. Regarding RQ 2 "Is the resulting ontology instrumental in structuring and presenting governance decisions in the realm of decentralization of the energy ecosystem", the ontology seems to capture the essentials of the peer-to-peer energy trading case, but this needs to more extensively validated, both with business consultants and in other domains.

VII. Conclusion

With this paper we presented DECENT, an ontological well founded conceptualization of the notion of decentralized governance. The resulting ontology proved to be instrumental in structuring and presenting governance in the realm of decentralization of the energy ecosystem. The ontology can be of use for consultants. With respect to our second goal, an ontology for *computational* governance, e.g. for use on a on-chain governance platform such as Tezos [4] the ontology needs to be more detailed, e.g. by including LegalRuleML or Symboleo, an ontology for measures, and facilities for process modelling, e.g. BPMN.

References

[1] J. F. Moore, *The death of competition: Leadership and strategy in the age of business ecosystems*. New York: HarperBusiness, 1996.

[2] S. Jairam, J. Gordijn, I. da Silva Torres, F. Kaya, and M. Makkes, "A decentralized fair governance model for permissionless blockchain systems."

[3] F. Kaya, Jaap, R. Wieringa, and M. Makkes, "Exploring governance in a decentralized energy trading eco-system," in *Proceedings of the33RD BLED e-conference: Enabling Technology for a Sustainable Society*, 2020. [Online]. Available: https://dise-lab.nl/wp-content/uploads/2021/05/Kaya-Bled-2020-final-version-fk-jg-2.pdf

[4] V. Allombert, M. Bourgoin, and J. Tesson, "Introduction to the tezos blockchain," 2019.

[5] H. M. Kim, M. Laskowski, and N. Nan, "A first step in the co-evolution of blockchain and ontologies: Towards engineering an ontology of governance at the blockchain protocol level," *arXiv preprint arXiv:1801.02027*, 2018.

[6] M.-C. Valiente Blázquez, D. Rozas, and S. Hassan, "Integration of ontologies with decentralized autonomous organizations development: A systematic review," 2020. [Online]. Available: https://eprints.ucm.es/id/eprint/62245/

[7] U. Chohan, "The decentralized autonomous organization and governance issues," *SSRN Electronic Journal*, 01 2017.

[8] A. Norta, L. Ma, Y. Duan, A. Rull, M. Kõlvart, and K. Taveter, "econtractual choreography-language properties towards cross-organizational business collaboration," *J. Internet Serv. Appl.*, vol. 6, no. 1, pp. 8:1–8:23, 2015. [Online]. Available: https://doi.org/10.1186/s13174-015-0023-7

[9] A. Norta, A. B. Othman, and K. Taveter, "Conflict-resolution lifecycles for governed decentralized autonomous organization collaboration," in *Proceedings of the 2015 2nd International Conference on Electronic Governance and Open Society: Challenges in Eurasia*, ser. EGOSE '15. New York, NY, USA: Association for Computing Machinery, 2015, p. 244–257. [Online]. Available: https://doi-org.vu-nl.idm.oclc.org/10.1145/2846012.2846052

[10] M. Fox and M. Grüninger, "Enterprise modelling," *Ai Mag*, vol. 19, 12 1997.

[11] Jaap and R. Wieringa, *E3value User Guide - Designing Your Ecosystem in a Digital World*, 1st ed. The Value Engineers, 2021.

[12] L. Zemmouchi-Ghomari and A. R. Ghomari, "Process of building reference ontology for higher education," vol. 3, 07 2013.

[13] B. Smith, *Ontology*. John Wiley & Sons, Ltd, 2004, ch. 11, pp. 153–166. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/9780470757017.ch11

[14] L. Schneider, "How to build a foundational ontology," in *KI 2003: Advances in Artificial Intelligence*, A. Günter, R. Kruse, and B. Neumann, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2003, pp. 120–134.

[15] F. Kaya, Jaap, R. Wieringa, and M. Makkes, "Governance in peer-to-peer networks is a design problem," in *Proceedings of the 14th International Workshop on Value Modelling and Business Ontologies (VMBO 2020)*, W. Laurier, G. Poels, B. Roelens, and H. Weigand, Eds. CEUR, 2020. [Online]. Available: https://dise-lab.nl/wp-content/uploads/2020/05/VMBO_2020.pdf

[16] T. R. Gruber, "Towards principles for the design of ontologies used for knowledge sharing," in *Formal Ontology in Conceptual Analysis and Knowledge Representation*, N. Guarino and R. Poli, Eds., Amsterdam, NL, 1994.

[17] W. N. Borst, J. M. Akkermans, and J. L. Top, "Engineering ontologies," *International Journal of Human-Computer Studies*, vol. 46, pp. 365–406, 1997.

[18] C. Feilmayr and W. Wöß, "An analysis of ontologies and their success factors for application to business," *Data Knowl. Eng.*, vol. 101, pp. 1–23, 2016.

[19] G. Guizzardi, G. Wagner, J. P. Almeida, and R. Guizzardi, "Towards ontological foundations for conceptual modeling: The unified foundational ontology (ufo) story," *Appl. Ontology*, vol. 10, pp. 259–271, 2015.

[20] J. F. Sowa, *Conceptual Structures: Information Processing in Mind and Machine*. USA: Addison-Wesley Longman Publishing Co., Inc., 1984.

[21] F. Steimann, "On the representation of roles in object-oriented and conceptual modelling," *Data Knowl. Eng.*, vol. 35, no. 1, p. 83–106, Oct. 2000. [Online]. Available: https://doi-org.vu-nl.idm.oclc.org/10.1016/S0169-023X(00)00023-9

[22] J. Konaté, P. Zaraté, A. Gueye, and G. Camilleri, "An ontology for collaborative decision making," in *Group Decision and Negotiation: A Multidisciplinary Perspective*, D. C. Morais, L. Fang, and M. Horita, Eds. Cham: Springer International Publishing, 2020, pp. 179–191.

[23] E. Kornyshova and R. Deneckère, "Decision-making ontology for information system engineering," in *Conceptual Modeling – ER 2010*, J. Parsons, M. Saeki, P. Shoval, C. Woo, and Y. Wand, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010, pp. 104–117.

[24] P. Nowara and N. Car, "Decision-o - the decision ontology," 2018.

[25] J.-L. Soubie and P. Zarate, "Distributed decision making: A proposal of support through cooperative systems," *Group Decision and Negotiation*, vol. 14, no. 2, pp. 147–158, 2005.

[26] T. W. Sandholm, *Distributed Rational Decision Making*. Cambridge, MA, USA: MIT Press, 1999, p. 201–258.

[27] M. Palmirani, G. Governatori, A. Rotolo, S. Tabet, H. Boley, and A. Paschke, "Legalruleml: Xml-based rules and norms," in *Rule-Based Modeling and Computing on the Semantic Web*, F. Olken, M. Palmirani, and D. Sottara, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 298–312.

[28] S. Sharifi, A. Parvizimosaed, D. Amyot, L. Logrippo, and J. Mylopoulos, "Symboleo: Towards a specification language for legal contracts," *2020 IEEE 28th International Requirements Engineering Conference (RE)*, pp. 364–369, 2020.

[29] C. Skelcher, "Jurisdictional integrity, polycentrism, and the design of democratic governance," *Governance*, vol. 18, no. 1, pp. 89–110, 2005.

[30] Y. Parag, J. Hamilton, V. White, and B. Hogan, "Network approach for local and community governance of energy: The case of oxfordshire," *Energy Policy*, vol. 62, pp. 1064–1077, 2013.

[31] O.-o. Poocharoen and B. K. Sovacool, "Exploring the challenges of energy and resources network governance," *Energy Policy*, vol. 42, pp. 409–418, 2012.

[32] C. Folke, T. Hahn, P. Olsson, and J. Norberg, "Adaptive governance of social-ecological systems," *Annu. Rev. Environ. Resour.*, vol. 30, pp. 441–473, 2005.

[33] A. Florini and B. K. Sovacool, "Who governs energy? the challenges facing global energy governance," *Energy Policy*, vol. 37, no. 12, pp. 5239–5248, 2009.

[34] M. Kottari and P. Roumeliotis, "Renewable energy governance challenges within a "puzzled" institutional map," in *Renewable energy governance*. Springer, 2013, pp. 233–248.

[35] A. M. Koster and J. M. Anderies, "Institutional factors that determine energy transitions: A comparative case study approach," in *Renewable Energy Governance*. Springer, 2013, pp. 33–61.

[36] G. IIAS, "The governance working group of the international institute of administrative sciences," 1996.

[37] S. Hammer, "Capacity to act: The critical determinant of local energy planning and program implementation," in *Fifth Urban Research Symposium, Cities and Climate Change: Responding to an Urgent Agenda*. Citeseer, 2009, pp. 28–30.

[38] T. M. Skjølsvold, M. Ryghaug, and J. Dugstad, "Building on norway's energy goldmine: Policies for expertise, export, and market efficiencies," in *Renewable Energy Governance*. Springer, 2013, pp. 337–349.

[39] S.-N. Boemi and A. M. Papadopoulos, "Times of recession: three different renewable energy stories from the mediterranean region," in *Renewable Energy Governance*. Springer, 2013, pp. 263–275.

[40] B. K. Sovacool, "An international comparison of four polycentric approaches to climate and energy governance," *Energy policy*, vol. 39, no. 6, pp. 3832–3844, 2011.

[41] D. Vangulick, B. Cornélusse, and D. Ernst, "Blockchain for peer-to-peer energy exchanges: design and recommendations," in *2018 Power Systems Computation Conference (PSCC)*. IEEE, 2018, pp. 1–7.

[42] S. J. McCormack and B. Norton, "The shadows cast by inadequate energy governance: Why more sun does not necessarily mean more photovoltaic electricity," in *Renewable Energy Governance*. Springer, 2014, pp. 277–293.

[43] ——, "The shadows cast by inadequate energy governance: Why more sun does not necessarily mean more photovoltaic electricity," in *Renewable Energy Governance*. Springer, 2013, pp. 277–293.

[44] Z. Zlatev, P. van Eck, R. Wieringa, and Jaap, "Goal-oriented re for e-services," in *Proceedings of the International Workshop in Service-oriented Requirements Engineering*, 2004.

[45] C. J. Koliba, R. M. Mills, and A. Zia, "Accountability in governance networks: An assessment of public, private, and nonprofit emergency management practices following hurricane katrina," *Public Administration Review*, vol. 71, no. 2, pp. 210–220, 2011. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1540-6210.2011.02332.x

[46] C. Burger and F. Mancebo, "Champagne and metal flowers: Who is invited to the wind generation party in france?" in *Renewable Energy Governance*. Springer, 2013, pp. 217–230.

[47] R. J. Wieringa, *Design science methodology for information systems and software engineering*. Springer, 2014.

[48] H. Rijgersberg, M. van Assem, and J. L. Top, "Ontology of units of measure and related concepts," *Semantic Web*, vol. 4, no. 1, pp. 3–13, 2013. [Online]. Available: https://doi.org/10.3233/SW-2012-0069

[49] J. M. Keil and S. Schindler, "Comparison and evaluation of ontologies for units of measurement," *Semantic Web*, vol. 10, pp. 1–19, 08 2018.

[50] H. Byrd and S. Matthewman, "Renewable energy in new zealand: the reluctance for resilience," in *Renewable Energy Governance*. Springer, 2013, pp. 137–153.

[51] C. Skanavis, C. Giannoulis, and V. Skanavis, "The significance of the environmental communication for the renewable energy governance scenario: Who decides for whom?" in *Renewable Energy Governance*. Springer, 2013, pp. 351–362.

[52] R. Hildingsson, J. Stripple, and A. Jordan, "Governing renewable energy in the eu: confronting a governance dilemma," *European Political Science*, vol. 11, no. 1, pp. 18–30, 2012.

[53] J. P. Faguet, *Decentralization and popular democracy: Governance from below in Bolivia*. University of Michigan Press, 2012.

[54] G. De Roo, J. Visser, and C. Zuidema, *Smart Methods for Environmental Externalities: Urban Planning, Environmental Health and Hygiene in the Netherlands*. Ashgate Publishing, Ltd., 2012.

[55] A. Rumbach, "Decentralization and small cities: Towards more effective urban disaster governance?" *Habitat International*, vol. 52, pp. 35–42, 2016.

[56] S. B. Pasquier and A. Saussay, "Progress implementing the IEA 25 energy efficiency policy recommendations," 2012.

[57] OMG, "Business process model and notation, version 2.0," 2011, Object Management Group (OMG). [Online]. Available: https://www.omg.org/spec/BPMN/2.0

[58] A. Goldthau, "Rethinking the governance of energy infrastructure: Scale, decentralization and polycentrism," *Energy Research & Social Science*, vol. 1, pp. 134–140, 2014.

[59] J. M. Hills and E. Michalena, "Geopolitics, climate change and energy governance: A grey area in the black sea region," in *Renewable Energy Governance*. Springer, 2013, pp. 249–261.

[60] T. Sousa, T. Soares, P. Pinson, F. Moret, T. Baroche, and E. Sorin, "Peer-to-peer and community-based markets: A comprehensive review," *Renewable and Sustainable Energy Reviews*, vol. 104, pp. 367–378, 2019.

[61] J. Kang, R. Yu, X. Huang, S. Maharjan, Y. Zhang, and E. Hossain, "Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 6, pp. 3154–3164, 2017.

[62] C. Hamilton and J. Kellett, "Renewable energy: urban centres lead the dance in australia?" in *Renewable Energy Governance*. Springer, 2013, pp. 63–79.

[63] K. Zhang, Y. Mao, S. Leng, S. Maharjan, Y. Zhang, A. Vinel, and M. Jonsson, "Incentive-driven energy trading in the smart grid," *IEEE Access*, vol. 4, pp. 1243–1257, 2016.

[64] J. Ruotsalainen, J. Karjalainen, M. Child, and S. Heinonen, "Culture, values, lifestyles, and power in energy futures: A critical peer-to-peer vision for renewable energy," *Energy Research & Social Science*, vol. 34, pp. 231–239, 2017.

[65] T. Morstyn, N. Farrell, S. J. Darby, and M. D. McCulloch, "Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants," *Nature Energy*, vol. 3, no. 2, pp. 94–101, 2018.

[66] EU, "Proposal for a regulation of the european parliament and of the council establishing the framework for achieving climate neutrality and amending regulation (eu) 2018/1999 (european climate law)," 2020. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588581905912&uri=CELEX:52020PC0080

[67] ——, "Masterplan for a competitive transformation of eu energy-intensive industries enabling a climate-neutral, circular economy by 2050," 2019. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/be308ba7-14da-11ea-8c1f-01aa75ed71a1/language-en

[68] ——, "Co2 emission performance standards for cars and vans," 2019. [Online]. Available: https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en