An approach to wicked problems in environmental policy making

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Abstract: - In environmental policy making, the objectives are part of the decision-making problem. Policy making for sustainable development involves problems with lack of clear and definitive problem formulation which are to be solved by various stakeholders who judge the solutions with different values. In addition, risks and uncertainties involving future events and risks and uncertainties associated to the costs, benefits or effectiveness of a given policy add complexity to the decision making. Because of these characteristics, modeling and assessment methods alone are not enough to provide an adequate decision making support. In other words, policy making involves the existence of "wicked problems. This paper presents an approach to support the solution of wicked problems in policy making for sustainable development.

Key-Words: - Policy making, policy design, design rational, wicked problems, ontologies

1 Introduction

Increasingly, policy makers are required to assess the impact of their policies in terms of sustainable development [1]. In policy making for sustainable development, the objectives are part of the decision-making problem. In other words, the formulation of the decision-making problem is the problem. Green policy making is accompanied not by one but by multiple decision-makers or stakeholders with individual goals and beliefs. Consequently, they tend to judge the policies according to their group or personal interests, their values and their preferences. Also, there is no definitive evaluation of costs or the criteria that indicates whether a solution is found [1]. This is because of the multiple dependencies among different environmental and sociotechnical systems, and the existence of uncertainties.

Summarizing, policy making for sustainable development is characterized by the following aspects:

1. Lack of clear and definitive problem formulation
2. Various stakeholders with different value judgments
3. Risks and uncertainties involving future events
4. Risks and uncertainties associated to the costs, benefits or effectiveness of a given policy

Because of these characteristics, modeling and assessment methods alone are not enough to provide an adequate decision making support. In other words, policy making involves the existence of "wicked problems.

There is a need to deal with policy design and formulation, evaluation from decision support point of view. For example, Alcántara argues about the advantages of decision support systems for energy and transportation policy formulation [2]. However, no details were given about the methodology or tools followed. Other related research is being undertaken by the European project SEAMLESS, which aims at developing a component-based framework for integrated assessment of agricultural and environmental policies, and technological innovations [3].

An example of environmental policies can be the introduction of renewable energies mechanisms i.e. renewable portfolio standard, feed in tariff, etc., or applying energy taxes that are not easy to be designed and accepted by the public. As seen in the simplified flowchart in Fig. 1, the process of making or modifying policies can be divided into three phases; 1) problem definition and policy analysis where the rationales of the changes or reformation of the policy design are defined with specific requirements of change, 2) policy planning and design that considers the modifications to be made by the designers or setting new goal based on the rationales of change and provide solution alternatives before testing their applicability, and 3) policy implementation and evaluation where the policy is tested in a real life situation or simulated by the tools provided by a policy making support system (PMSS). The policy making can, also, be thought as a four-step cycle model for carrying out change *plan–do–check–act* cycle, PDCA, as shown in the Fig 1.

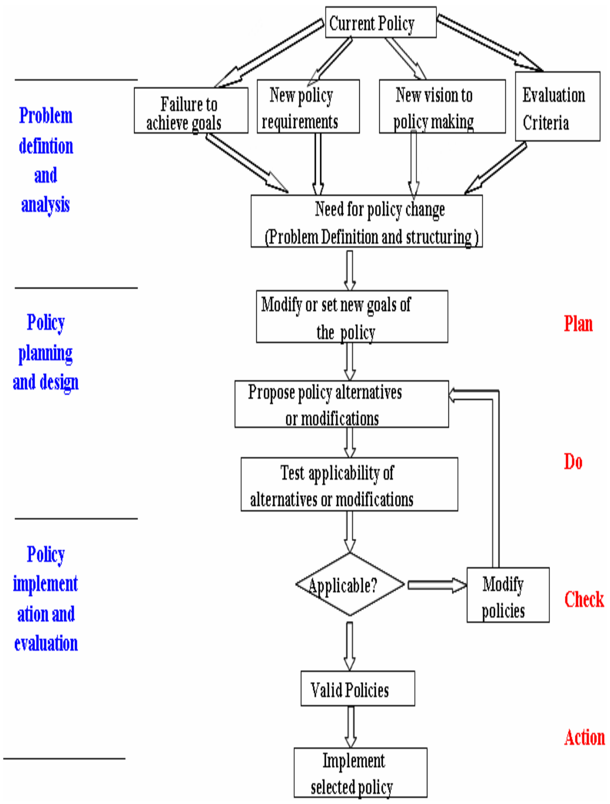

Fig. 1. Simplified Policy Making flowchart

2 Wicked problems in environmental policy making

Policy, as defined in [4] "is a course of action of a governmental body, where a course of action could be a law, a regulation, a project, or other public decision." Policy making can be categorized to follow the naturalistic decision theory, as the policies and decisions are made based on situation assessment, understanding of problem surrounding and investigating the consequences of carrying out specific decision [5].

Invariably, the policy maker faces the so-called wicked problems. For instance, wicked problems in natural resource management have the following characteristics [6]:

1. There is not single correct problem formulation. In other words, each stakeholder defines the problem differently.
2. Outcomes are not scientifically predictable.
3. The decision maker cannot know when all the solutions have been explored
4. Solutions are generally only more or less useful, rather than good or bad
5. Ecosystems, communities of interest, funds, organizational capabilities, etc. combine with stakeholder demands in particular ways

Rittel and Weber list 10 characteristics of wicked problems [7]:

1. There is no definitive formulation of a wicked problem. Wicked problems have no definitive formulation. In other words, wicked problems lack definitive information for understanding and solving the problem.
2. Wicked problems have no stopping rule. Wicked problems have no stopping criteria to know whether a solution has been found.
3. Solutions to wicked problems are not true-or-false, but good-or-bad. Wicked problems involve many stakeholders who are equally entitled to criticize the solutions. Their judgments may differ according to the group of personal interests, value-sets and their ideological preferences.
4. There is no immediate and no ultimate test of a solution to a wicked problem. There is no way to know how well a solution has been.
5. There is no opportunity to learn by trial and error. Every solution to a wicked problem is a "one-shot operation". In other words, the actions in a given solution cannot be undone. Every attempt to reverse the decision or to correct the consequences of a given decision poses another set of wicked problems.
6. Wicked problems do not have an enumerable set of potential solutions.

There are no criteria to prove that all the solutions have been found.

7. Every wicked problem is unique. There are no rules to classify wicked problems in terms of quite-well-specified attributes.
8. Every wicked problem can be considered to be a symptom of another problem. Removal of the cause of a problem poses another problem of which the original problem is a symptom. For example, "crime in the streets" can be considered as a symptom of poverty.
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem resolution. There are several ways of refuting a hypothesis.
10. The planner has no right to be wrong. In wicked problems, planners are liable for the consequences of the actions that they generate.

Policy formulation has associated a degree of uncertainty about the future, because assumptions about the economy, technology and society can become invalid [8]. The policies are then conditional to the validity of those assumptions.

Incidentally, this is the same kind of problems that commonly occur in many engineering design situations. A number of methods and their implementation have been proposed to assist in the solution of wicked design problems. Design rationale methods have been developed to capture the argumentation (pros and cons) of alternatives that are proposed as potential solutions of a design problem. Some design rationale techniques define knowledge about the history of design decisions taken by the designers. Some others focus on the design space (the relations between design alternatives, design decisions that are gradually developed).

Among these, IBIS is probably the most well-known method. Rigorously speaking, IBIS includes both a methodology and a knowledge model. The methodology starts with problems for which solutions are proposed and then evaluated with supporting or refuting arguments. The knowledge model defines a graph composed of three kinds of nodes, namely issues (problems), positions (potential solutions), and arguments. Eight types of edges are defined to add semantic content to the graph, namely supports, objects-to, replaces, responds-to, generalizes, specializes, questions, and suggested-by. Fig. 2 shows an example of an IBIS graph.

3 Methodology

Similar to IBIS, policy making can be seen as a process that starts by defining the goals of the policy making (the problem) and then continues by proposing candidate-policies (solutions), some of which are rejected and some others are refined until they are accepted. During this process, candidate-policies are evaluated by with supporting or refuting arguments.

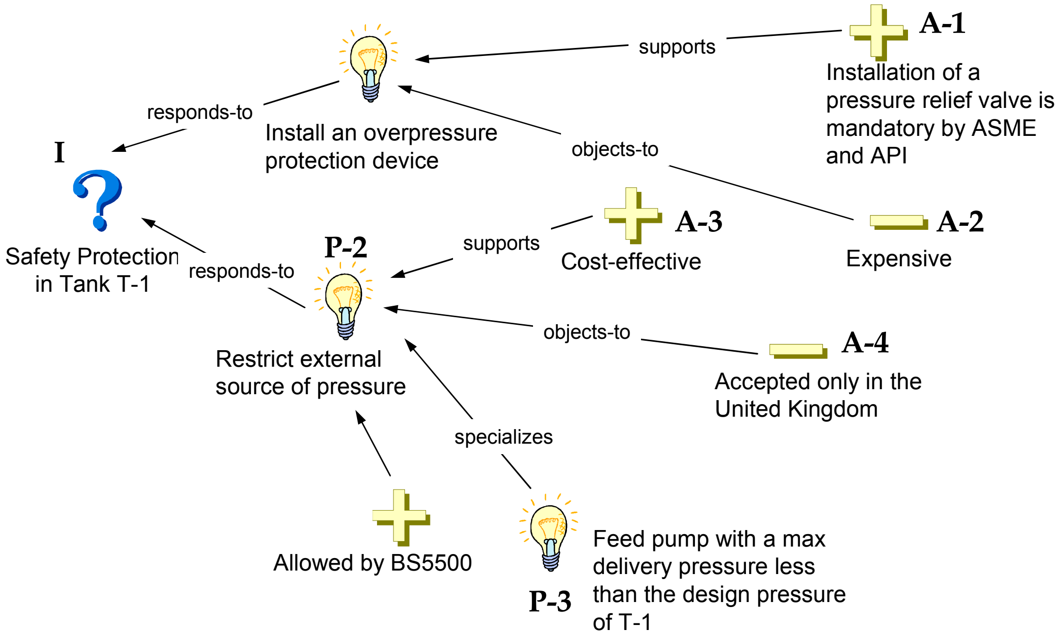

Fig. 2. A fragment of an IBIS graph of the design of a safety protection system

Here we consider two possible uses of the rejected and accepted policies. Firstly, some policies may become relevant when economic, environmental, technological or political conditions change.

Secondly, draft policies can be used as the basis for new ones. For example, a policy maker can search past policies that are relevant to a current situation. $=(P,R,S,A,C)$.

The methodology for dealing with wicked policy-making problems is extends IBIS by making assumptions or constraints explicit. Note for example, how in Fig. 2, the argument A-4 that objects to position P-2 can become invalid when the target country becomes the United Kingdom, for which position P-2 is preferred over P-1.

By making constraints and assumptions explicit, this allows the policy maker to explore the reuse of previous accepted and discarded policy alternatives. For example, a given policy that is based on a scenario for biomass as a source of chemicals is likely to include a constraint such as *biomass becomes competitive for chemicals production when the oil price is at or above P$ per barrel.*

Also, explicit assumptions helps the stakeholders recognize that external factors such as technology or the oil price in the previous example, are not explicitly parameterized in an environmental model but can be related to some of the model inputs [9].

The space of proposed policies is represented as a decision graph composed by the following elements.

1. A problem $P=\{p_1,\ldots,p_n\}$

2. A set of requirements that are used to define the problem. $R=\{r_1,\ldots,r_n\}$

3. A set of solutions (draft policies) that satisfy the requirements of P. $S=\{s_1,\ldots,s_n\}$

4. Arguments that support or invalidate each solution in S. $A=\{a_1,\ldots,a_n\}$

5. A set of constraints which determine the validity of an argument in A in relation to a solution in S. $C=\{c_1,\ldots,c_n\}$

6. The *define* relation associates problems and requirements

$d\subseteq P\times R$:defines. P ⊵ R

7. The *responds* relation maps a solution with a given problem. $r\subseteq S\times P$

8. Arguments are linked to their solutions by means of the *supports* $s\subseteq A\times S$ and *objects* $o\subseteq A\times S$ relations.

9. The *restricts* relation associates constraints to arguments: $q\subseteq C\times A$

10. The *raises_problem* relation is used for solutions that generate a subproblem that should be solved for the solution to be effective.

The graph has a tree-shape with solutions as

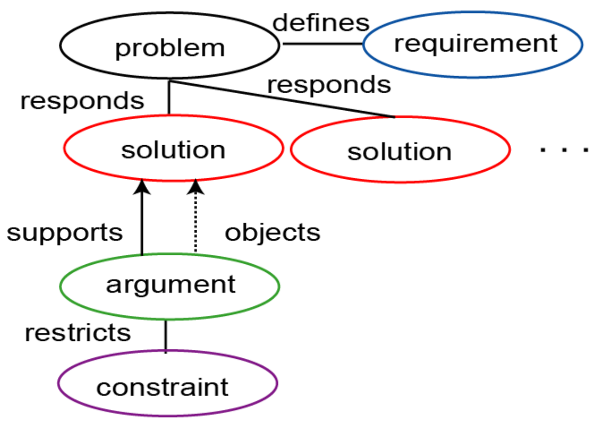

Fig. 3. Structure of a decision graph

main branches (Fig. 3).

In a given decision graph, one of the solutions (draft policies) will be selected and possibly implemented (the approval status is final). However, there will be a number of other possible solutions (draft policies) that were not selected but which are kept for future policies. In other words, their approval status is "draft".

A decision graph based on the policy instruments discussed in [10] is shown in Fig. 4. The problem is to formulate a policy for promoting electricity generation from renewable energy resources. Two solutions are presented, namely bidding schemes and feed-in tariffs (other solutions could include information devices or voluntary agreements).

An example of how to represent a solution that generates a subproblem is shown in Fig. 5. The example is based on the discussion of policies aimed at the reduction of emissions generated by motorized two-wheeled vehicle in India [22]. Part of the solutions proposed include the minimization of other transport impacts such as the use of kerosene mixed with gasoline. One way to remove fuel adulteration is to remove the subsidies for kerosene. However, this is likely to cause kerosene to become unaffordable for the large number of low-income households that use kerosene as a cooking fuel. Consequently, such households may opt for less efficient fuels such as firewood which affect the effectiveness of the proposed solution.

4 Guiding the generation of the solution space

Based on the Multi-dimensional formalism (MDF) proposed by Batres et al. [11], problems, solutions or constraints can be described in terms of properties of systems. Each system has structural, behavioral, and operational descriptions.

Structural descriptions of a system are characterized by the interconnections between system components. For example, the structural description of value chains would represent a network of suppliers, producers, consumers, research institutions, government and recycling facilities.

The behavior of a system indicates how a system reacts in its relation to other systems. For example, the behavior of a value chain refers to the changes in the flows of material, energy, emissions to the environment, and money. Other examples are changes in consumer preferences, changes in the flow of requested raw materials.

Operational aspects define the those activities that are possible during the implementation of policies. For example, an operational solution may be the elimination of subsidies.

4.1 Reuse of past draft policies

Draft policies, including those rejected in past projects, can be used as the basis for new ones. The approach is as follows.

Step1 Define the new problem P_{new} and its requirements R_{new}

Step2 Compare the pairs of R_{new} and R_{old} to check if the requirements of the new problem are subsumed by the requirements in an old problem ($R_{new} \subseteq R_{old}$)

Step3 If $R_{new} \subseteq R_{old}$ then extract the solutions S_{old} and arguments A_{old} . Let $S_{new} = S_{old}$ and

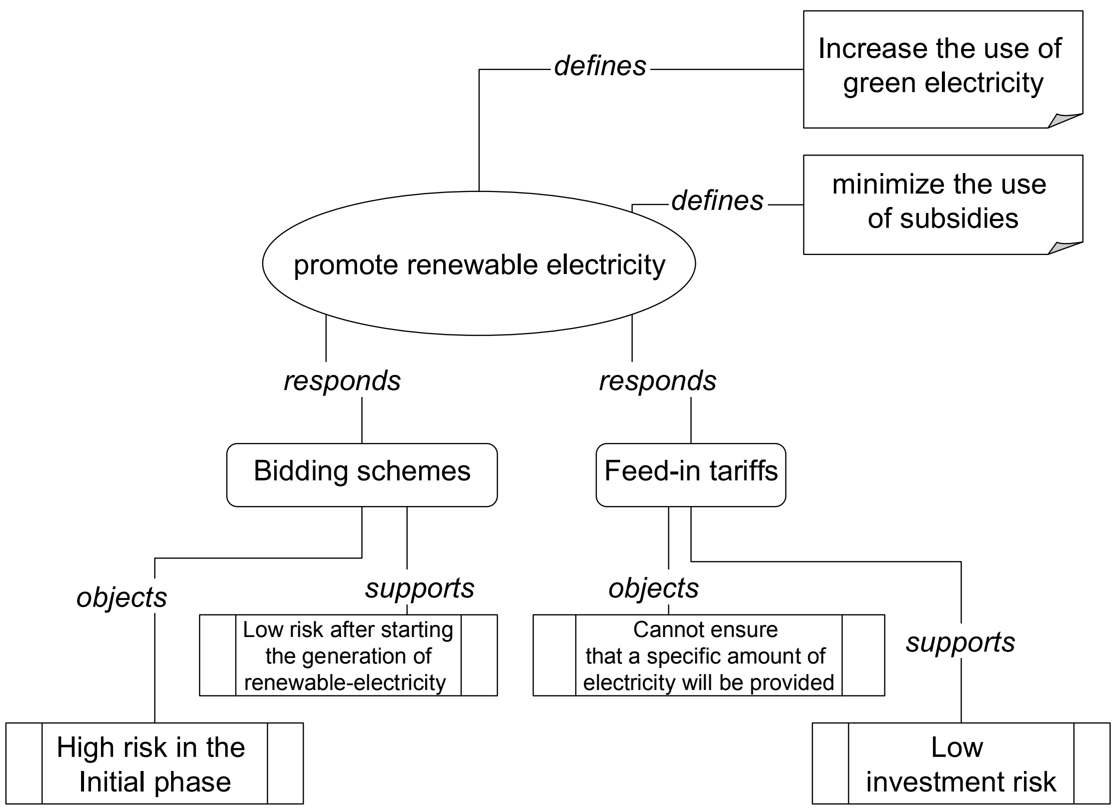

Fig. 4. Example of a decision graph for a policy on the instruments to promote renewable energy

$A_{new} = A_{old}$

Step4 Check each C_{old} against the new requirements R_{new}. Let $C_{new} = C_{old}$

Step5 For those solutions in which the constraints apply check the arguments A_{new}

Step6 Select a solution from S_{new}

defined with the use of the subclass relation. A class is a subclass of another class if every member of the subclass is also a member of the superclass.

When building an ontology for a certain policy making project, it can be avoided to start from stractch by using a common set of definitions grouped in what is referred to as an upper ontology. Upper ontologies define top-level classes such as physical objects, activities, part-whole and connectivity relations, from which more specific classes and relations can be defined.

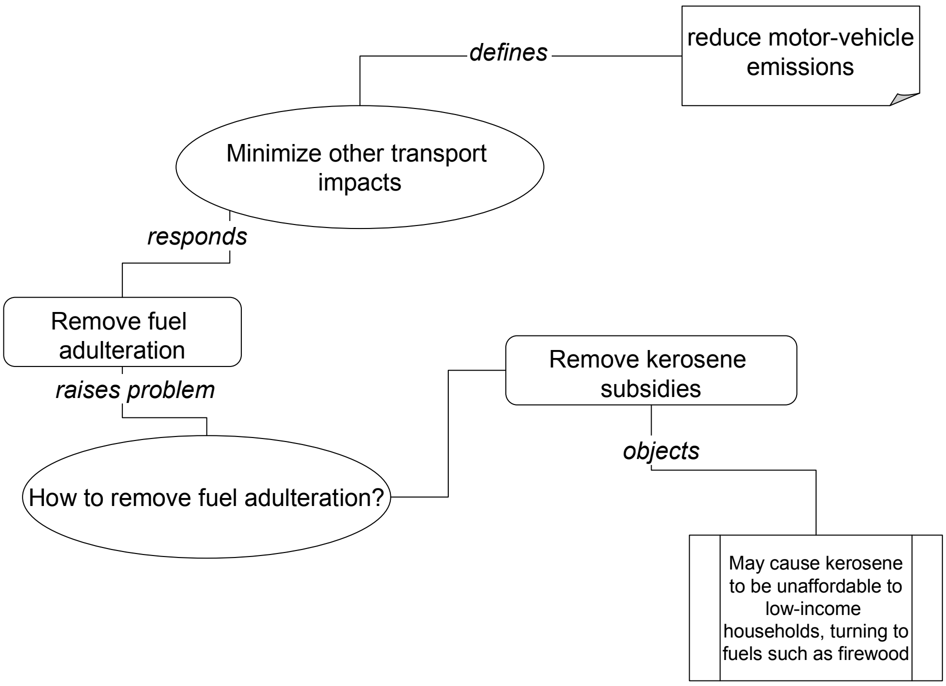

Fig. 5. A decision graph in which a solution raises a new problem

5 Ontologies

Information systems can be developed to support the effective reuse of the knowledge which is embedded in the decision graph. This information systems will require a common, unambiguous, and shared meaning of the "things" described in the problem, solutions, arguments and constraints. This can be possible by means of the so called ontologies.

In general, ontologies describe a shared and common understanding of a domain that can be communicated between people and information systems. We construct an ontology by defining classes of things, their taxonomy, the possible relations between things and axioms for those relations. A class represents a category of things that share a set of properties. A relation is a function that maps its arguments to a Boolean value of true or false. Examples of relations are less_than, connected_to, and part_of. Class taxonomies are

Specifically, ISO 15926 Part 2 (standardized as ISO 15926-2:2003) specifies an ontology for long-term data integration, access and exchange (ISO-TC184, 2003). It was developed in ISO TC184/SC4-Industrial Data by the EPISTLE consortium (1993-2003) and designed to support the evolution of data through time [12].

The upper ontology can be used to define classes and properties that are used in a specific policy making problem. For example, the *compound* class can be extended to include things such as classes of vegetal biomass as shown in Fig. 6.

5.1 Main classes in the ontology

thing is the root concept in the ontology which is classified as abstract_object and possible_individual. A thing is anything that is or may be thought about or perceived, including material and non-material

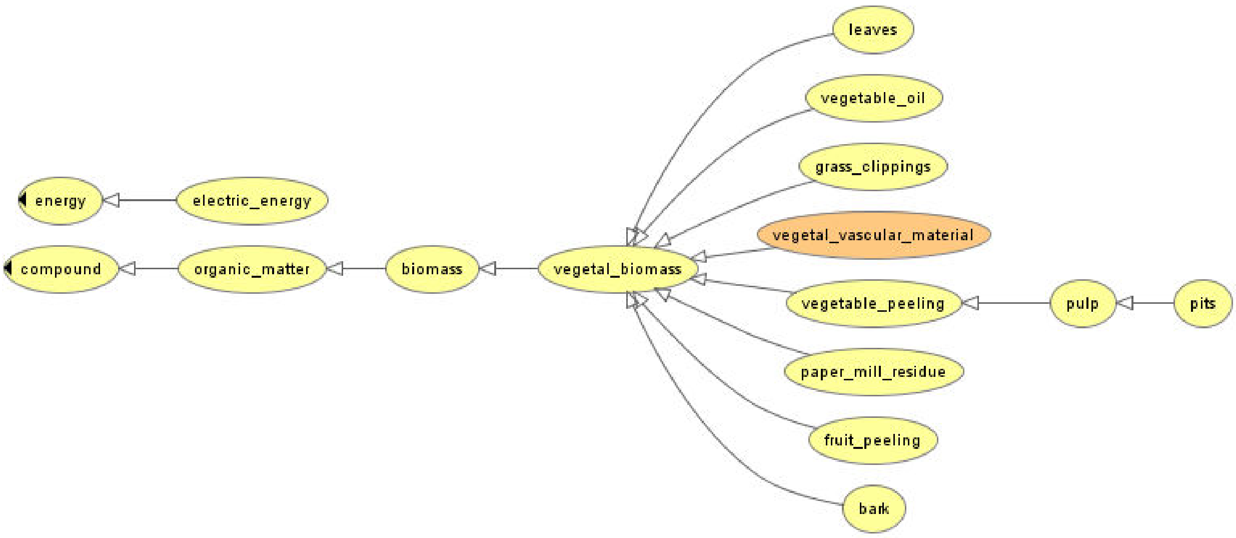

Fig. 6. A class hierarchy of vegetal biomass

objects, ideas, and activities. Every thing is either a possible_individual, or an abstract_object.

Members of possible_individual (Fig. 7) are entities that exist in space and time, including physical objects like a natural-resource or non-physical like a policy. A possible_individual has a life cycle bounded by beginning and ending events.

Individuals that belong to abstract_object can be said to exist in the same sense as mathematical entities such as numbers or sets but they cannot exist at a particular place and time. possible_individual is has a number of overlapping subtypes: arranged_individual, actual_individual, whole_life_individual, physical_object, activity, period_in_time and event.

Instances of arranged_individual have parts each of which plays a distinct role with respect to the whole. For example, a supply chain is an instance of arranged_individual. A role indicates what some thing has to do with an activity. A certain material can play the role of product in a given manufacturing process but it could also be play the role of feedstock for a recycling process downstream.

An actual_individual is a possible_individual that exists in the present, past, or future of our universe, as opposed to some imagined universe. The computer used to edit this paper is an actual_individual.

A whole_life_individual is a possible_individual that is a member of a subclass of possible_individual and is not a temporal part of any other possible_individual that is also a member of the same subclass of possible_individual.

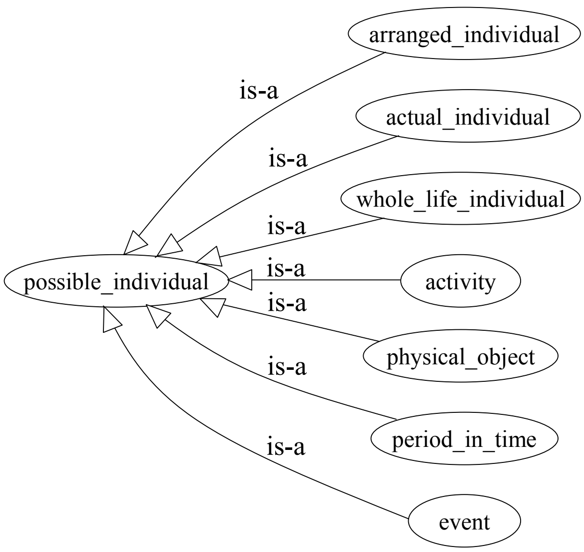

Fig. 7. Subclasses of possible individual

5.2 Activities and scenarios

An activity is a possible_individual that brings about change by causing an event. Like possible individuals, activities can have a life cycle bounded by beginning and ending events. An event is a possible_individual that has zero extent in time, which means that it occurs at an instant in time. A point_in_time is an event that is the whole space extension with zero extent in time. A period_in_time is a possible_individual that is the whole space extension for part of time.

Aspects related to activities include:

1. A description of the sub-activities that compose the activity
2. All the conditions of an activity that must be satisfied in order for that activity to take place
3. The participants required by an activity
4. The sequence of activities
5. The constraints and requirements of the activity
6. The characteristics of the things produced by or used in the activity
7. The agent that implements the activity (politician, organizations)

Scenarios can be described in terms of a causal relation (cause_of_event) which links an activity to an event which can be the beginning of another activity. For example, Fig. 8 shows the causality of a fragment of a scenario of a causal chain analysis of a Peterborough's Local Transport Plan [13].

The participation relation is used to express that a possible_individual is involved in an activity.

6 Policy Making Support Systems

The policy making support system is a computer-based environment that integrate tools and methods to enable the policy makers formulate, reuse, and judge policies from environmental, economical, technological and societal points of views [14-16]. Societal knowledge includes willingness to accept new policies, groups perception of the planned actions, their preferences, etc. Decisions about application of different technologies in certain localities rely mainly on technological aspects such as capacities, noise and costs. The economical concerns are of prior importance for policy makers as well as local population. Therefore, the economical data of a new policy and its effects on society are of great importance. Economical data includes project cost estimations, taxes, subsides. Examples of environmental knowledge are possible expected pollution to the local area, noise level of the project, generated traffic.

6.1 Why PMSS are needed

It is almost impractical to split the 'technical' aspects of applying policies from their design. Technical aspects includes scientific, economic, sociological, and feasibility effects of the policy proposal. For example, populations like to have better environment with less or no expenses and consequently oppose any policy change that will make them pay. Therefore, building PMSS is of crucial importance to help in designing, analyzing, testing environmental policies, checking their feasibilities, and determining the potential problems that may hinder or stop the decision making process in advance.

6.2 Requirements of future PMSS

The system should help the policy makers to formulate, test policies on their consistency to the society. Also the system has to support the policy maker in modifying the policy made. In the following two sections the requirements that need to be included in any new PMSS to support both phases of policy making.

6.2.1 Policy Design requirements

During the Policy design phase the PMSS should support policy makers by enabling them to:

- Provide methods for discourse, argumentation and critiquing of alternative policies
- Provide tools for generating some of the knowledge required in the evaluation of the policies. For example, life-cycle assessment for a measure of the environmental impact of the current state-of-affairs.
- Provide diverse of policy scenarios by allowing the testing of optimistic and pessimistic scenarios of applying the policy (such as complete refusal by public or complete acceptance).
- Design specific performance measures and impacts to the public, economy, environment, and other socio-technical systems
- Analyze the risk of the new policy to human health, the environment, economy, and at the same time quantify the effects of measures to reduce these risks.
- Insure that policy made take into account the concerns of politicians to overcome policies rejection i.e., policy feasibility [17].
- Develop various indicators, which are able to describe the environmental risk of the policy application [18].

6.2.2 Policy Application requirements

During the policy application phase the PMSS should support policy makers by providing tools that can:

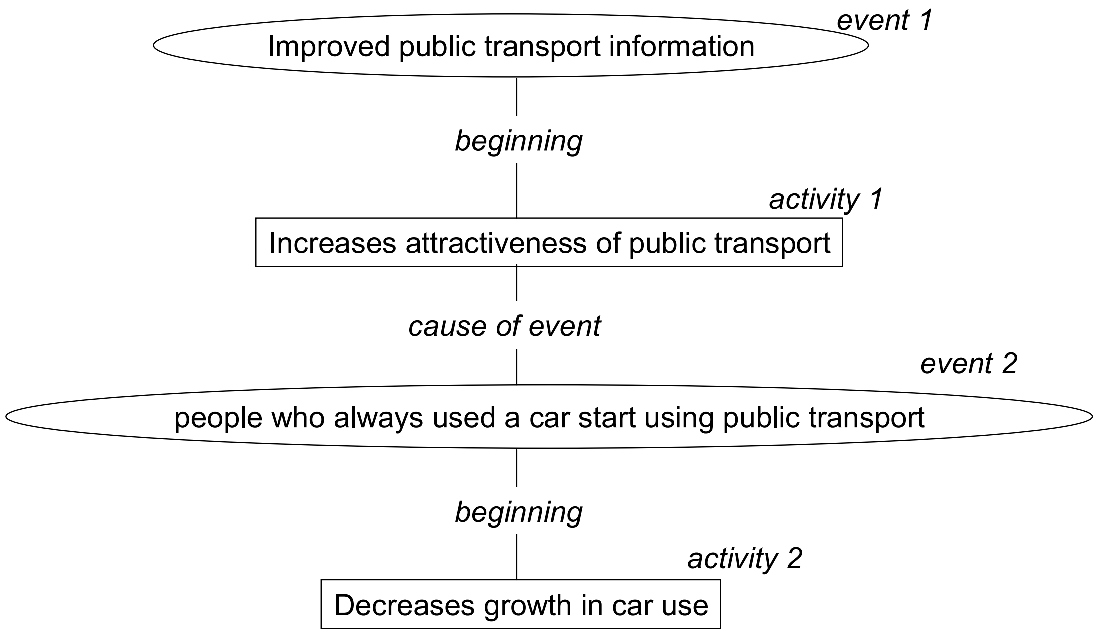

Fig. 8. A causal chain in terms of the concepts of the upper ontology

- Test the environmental merits of a policy application (how much of environmental impacts can be reduced)
- Define the possible economical effects of the policy made on the application domain (country, region, city) as well as public (such as tax increasing or reduction)
- Compare the current policies with the assumed policies through specific performance measures and their impacts to the public, economy, environment, etc.
- Investigate the long-term effects of given policies and changes in policies [5]
- The ability to perform policy measure and evaluation and reuse all or part of current policies in the development of new policies [3].

7 Prototype implementation

The upper ontology is implemented in the OWL ontology language [19] which is being used worldwide to encode knowledge and enable interoperability in distributed computer systems [20].

The elements for the construction of the decision graph are also implemented in OWL. In the implementation the *solution* class is defined as a subclass of *activity*.

For example, the causal chain of Fig. 8 is represented as follows:

```
<activity rdf:ID="activity_1">
    <beginning>
      <event rdf:ID="event_1"/>
    </beginning>
    <cause_of_event rdf:resource="#event_2"/>
</activity>

<event rdf:ID="event_2"/>

<activity rdf:ID="activity_2">
    <beginning rdf:resource="#event_2"/>
</activity>
```

Queries to the ontology are passed to JTP (Java Theorem Prover) which is a reasoning system that can derive inferences from knowledge encoded in the OWL language. JTP is composed of a number of reasoners that implement algorithms such as generalized modus ponens, backward-chaining, and forward chaining and unification [21].

JTP translates each OWL statement into a CLIF sentence of the form (PropertyValue Value Predicate Subject Object). Then it simplifies those CLIF sentences using a series of axioms that define OWL semantics. OWL statements are finally converted to the form (Predicate Subject Object). Queries are formulated in CLIF, where variables are preceded by a question mark. For example, in order to obtain the classes of vegetal biomass (Fig. 6), the query is formulated as This list of classes is obtained by querying the JTP knowledge base with the following query: `(rdfs:subClassOf ?x lce:vegetal_biomass)`. If one is interested in all kinds of biomass the query would be formulated as: `(rdfs:subClassOf ?x lce:`

biomass), in which vegetal_biomass is a subclass of biomass.

One can also perform queries to find decision graphs or fragments of decision graphs. For example, a query for a problem that has a solution involving the kerosene is as follows:

```
(and (rdf:type ?problem dr:problem)
   (dr:responds ?solution ?problem)
   (lis:participation ?solution ?object)
   (rdfs:subClassOf ?object mat:kerosene))
```

8 Conclusion

The underlying thesis of this paper is that policy making for sustainable development involves wicked problems which are characterized a with lack of clear and definitive problem formulation, multiple stakeholders, different value judgments and several risks and uncertainties. An approach to deal with this kind of problems was presented based on techniques for design rationale.

Decision graphs are used to capture the different candidate-policies (solutions) then critiqued with supporting or refuting arguments. Ontologies are used to represent aspects of the policy that are communicated between people and diverse software tools.

This paper also presented a general description of the general requirements to be taken into consideration when we develop PMSS . The PMSS needs to include tools and methods that may help the policy makers to decide about the practicability of certain policy from various perspectives.

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