AGENT-BASED AS AN ALTERNATIVE TO PROGNOSTIC MODELING OF SAFETY RISKS IN HYDROGEN ENERGY SCENARIOS

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ABSTRACT

Interest in the future is not new. Economic constraints and acceptability considerations of today compel decision-makers from industry and authorities to speculate on possible safety risks originating from a hydrogen economy developed in the future. Tools that support thinking about the long-term consequences of today's actions and resulting technical systems are usually prognostic, based on data from past performance of past or current systems. It has become convention to assume that the performance of future systems in future environments can be accommodated in the uncertainties of such prognostic models resulting from sensitivity studies. This paper presents an alternative approach to modeling future systems, based on narratives about the future. Such narratives, based on the actions and interactions of individual "agents", are powerful means for addressing anxiety about engaging the imagination in order to prepare for events that are likely to occur, detect critical conditions and to thus achieve desirable outcomes. This is the methodological base of Agent-Based Models (ABM) and this paper will present the approach, discuss its strengths and weaknesses, and present a preliminary application to modeling safety risks related to energy scenarios in a possible future hydrogen economy.

1. INTRODUCTION

In times in which global conscience about the impact of greenhouse gasses and the finite nature of fossil fuels grows, the possibility to use hydrogen as an energy carrier has caught the interest of policy makers. A main concern about hydrogen is its safety and acceptance as a widely spread application, such as its use for transport applications, integrated in daily life activities.

To determine the safety of energy technologies, analytical models are traditionally used based on statistical data from physically existing or at least already largely designed systems, which generate prognostic - quantitative, semi-quantitative and qualitative - estimates on some performance measures. However, a widely spread hydrogen economy does not yet exist and therefore neither extended historical statistics nor design schemes are currently available. The core feature of these analytical models is to come to a single best description of the system of interest, followed by the development of a policy based on that model that is best in the context of the model's mathematical expression. Typically, a best policy following from that model is the policy that optimizes some cost or utility function for that model. Although this approach seems to be obvious, its predictive value is hard to verify [1]. All such approaches are based on the basic assumption of rational actors following predictable rules. This paradigm might be a sufficiently valid modeling assumption for relatively homogenous and hierarchically organized societies at a certain period of time (e.g. the governmental and industrial elite in Western Europe during the 1950s or the policy making institutions in the Soviet Union during the 1970s). It is, however, certainly not applicable to model the underlying risk acceptance criteria of such highly diverse and interconnected societies as the ones, which would be exposed to a possible future hydrogen economy. Consequently, there is a need for approaches that are capable of dealing more realistically with modeling the safety risks originating from such a widely spread and interconnected complex system.

2. OBJECTIVE

An important weakness of current approaches to model future energy scenarios, is the inherent believe that a projection of the contemporary Rational Actor Paradigm (RAP) to the future is justified.

The RAP claims that an actor involved in any level of a decision making process will resort to a minimax strategy. Antagonists, e.g. regulators, industry, consumers, NGOs, will seek to maximize minimum gains while minimizing maximum losses. RAP holds largely true for decision making problems whose possible outcomes are dominated by economical parameters, but significantly distorts the model for a problem which is largely determined by values which are not well represented within econometrics, such as behavioral and cultural factors. In the RAP understanding of how the performance of societies can be modeled, agents participating in a society act as a homo oeconomicus. The homo oeconomicus tries to achieve Nash equilibriums in his capital economics. According to Nash's definition, interacting agents are in equilibrium if a change in strategies by any one of them would lead that agent to earn less than if he remained with his current strategy. The assumption that agents in sociopolitical models search for Nash equilibriums in their capital is at the basis for many General Equilibrium (GE) models, such as the Computational General Equilibrium (CGE) models [2, 3]. The limitation of the CGE models is that they do not provide sufficient tools to allow emergent events within possible scenarios during the transformation from one equilibrium to the other.

In this work, to overcome the above mentioned limitations of traditional prognostic methods, an alternative approach will be examined on its applicability for energy scenario modeling, specifically hydrogen: Agent-based Modeling (ABM). ABM distinguishes itself from traditional scenario modeling approaches by the inherent assumption of adaptivity and learning capacities of the actors ("agents") within a scenario. Complexity will be introduced as an important modeling concept rather than as an obstacle to be simplified by rigid mathematical modeling. The goal of ABM is not to find means to generate predictions for parameters within energy scenario models, but to understand the influence of human behavioral factors on energy pathways followed by societies and detect critical conditions. Ultimately, this should lead to a more realistic representation of developments following a certain policy.

3. WEAKNESSES OF EXISTING APPROACHES TO MODEL HYDROGEN ECONOMY SCENARIOS: CGE MODELS

There is a large diversity of opinions and visions on the type and extent of safety risks prevailing within a hydrogen economy. Arguments in favor of a hydrogen economy are ecological benefits, increase of independence of the fossil fuel market and the possibility to decentralize the energy infrastructure [4,5,6]. Opponents often stress the high risk potential of hydrogen ignition and detonation as compared to fossil fuels. Other issues considered relevant are the difficult storage and transport of hydrogen, the costs in application of hydrogen, etc.

The principle of hazard is positioned in a web of opportunities and weaknesses. Hazards of proposed technologies are a human matter: technology is not an exogenous factor, technology is designed and engineered by humans, and so are its safety measures and thus they are endogenous to a society. Therefore it would theoretically be possible to achieve a safety level leading to zero accidents involving injuries, casualties and economic losses, as it is produced by human efforts. But the amount of technological measures to be taken to achieve such a level of direct safety has a price, both in terms of capital as well as in terms of energy.

Furthermore, hydrogen is not an energy source, but an energy carrier. Abundant amounts of hydrogen are available on the planet, yet conditions on earth are such that hydrogen is not available freely, but as a chemical component of water. Splitting molecules to make the hydrogen free and then protecting it from the atmosphere is consuming a significant amount of energy. Since this energy is coming from other energy sources with their specific technologies and safety and ecology related consequences, these indirect effects of a hydrogen economy are also risk criteria.

In principle, the application of for example a CGE model for predicting economic perspectives could give reliable results if the RAP holds sufficiently true and human beings consequently limit their behavior to that of a homo oeconomicus. This should be true for all stakeholders in a society (authorities, industry, consumers).

However, as mentioned, the values which are at stake when considering the development of a hydrogen infrastructure are not just limited to economical growth and financial risks for investors: Despite large uncertainties, there are worldwide concerns about possible catastrophic effects of global warming due to burning of fossil fuels, and heuristic reasoning of non-hydrogen-experts may cause concerns about hydrogen based on events from the past, like the Hindenburg accident. Further, governments in the US and Europe have a strong preference for independency from foreign fuel sources, e.g. [7], and some argue that hydrogen could instead be produced from largely domestic resources.

This shows that social factors and values, which are often not endogenously represented in the monetary CGE approach based on capital game equilibriums, are of importance for hydrogen scenario developments.

4. SCENARIO MODELING: ADAPTIVE BEHAVIOR OF ACTING AGENTS

4.1 Short history of behavioral studying sciences

The split-up of social and natural sciences has lead to different opposing theories about human behavior: The Darwinist approach [8, 9] argues that even a so seemingly human phenomenon as morality is the product of natural selection and thus based on deterministic and, at least in theory, quantifiable principles. This work follows the competing and more elaborated alternative view on human behavior as developed by evolutionary researchers [10], unifying hypotheses from different scientific fields in a reasonable way:

- The learning capacities provided by the neural architecture of humans include specializations that evolved in history among foraging ancestors. Those capacities helped our ancestors to solve specific adaptive problems posed by the statistical and causal structure of the ancestral world.
- As these specializations constitute at least a part of the neural circuitry through which learning and development proceed, they introduce evolved content into the brain that predisposes the individual to behave according to patterns that would have been adaptive given the recurrent structure of the world in which our ancestors lived.
- These specializations influence the content of contemporary cultural elements that are obtained from and transmitted to other individuals in a way that reflect partly the design and operation of these evolved problem-solving circuits [11].

4.2 Example: the interpretation of the Nash equilibrium

Principles of learning and adaptivity are essential for assessing possible future scenarios based on not yet available technologies, as it is the case with hydrogen as an energy carrier. Application of the GE approach inherently assumes that a competitive monetary price is decisive for acceptance of, for example, a hydrogen fueled car. Although costs of a new technology are certainly relevant for public acceptance, the GE approach simply assumes that a human being has a drive to buy new technology due to maximization of utility. In biology, where Darwinian fitness replaces the "utility" in the traditional economical approach, the application of the Nash equilibrium is more successful [12] as the concept of 'utility' is replaced by 'fitness'. In that scope, monetary economics are much more of a cultural layer on top of the evolutionary explainable behavioral economics, while the behavioral economics seem to be more the hard-wired representation of evolutionary history of species. The understanding of this lower behavioral layer is important in order to explain the failures of rigid classic interpretations of monetary economics.

4.3 Example of bounds to the classic economic interpretation of the Nash equilibrium on maximization of utility: Altruism

One important type of human behavior, which is in conflict with the traditional economic idea of maximization of capital utility, is altruism. In biology, there was a belief that altruism can be interpreted as a strategy related to genetic reproduction to secure one's own genes [9] and thus serve Darwinian fitness. This suggests that altruism would only make sense among family members. This rigid selfish interpretation of survival of the fittest has failed in proving itself in human societies; it seems to have more success when applied to other animal species. It has been shown that in human societies, altruism occurs also among strangers [13] and therefore altruism seems to be more closely related to cultural group selections. Recent models of cultural group selection are based on the idea that norms and institutions are sustained by punishment. If altruistic punishment is not an option within a group, then cultural group selection will not be able to generate cooperation in large groups [14]. The ability to develop social norms that apply to groups of humans that are not genetically related, as well as the ability to enforce these norms through altruistic punishment is one of the distinguishing characteristics of the human species.

A first conclusion that the adoption of economic behavior according to the classic GE approach is culturally influenced is supported by a recent study in 15 small-scale countries [15]. This research shows that preferences in economic choices are shaped by the economic and social interactions of everyday life.

In summary, there is large evidence available that predictions of the effects of changing economic policies and institutions that do not take into account behavioral change are questionable. Cultural dynamics and individual adaptivity are essential in realistic economic forecasts of possible energy scenarios.

5. DESIGN OF HUMAN ACTORS IN ENERGY SCENARIOS

5.1 Introduction

As mentioned earlier, prognostic models fall short in two main ways [16]:

- Interactions between various computational entities are too rigidly defined;
- There are insufficient mechanisms available for representing the system's inherent organizational structure.

As an alternative, a relatively young synthesis called Agent-based Modeling (ABM) has gained attention in the last years. An agent-based model is an assembly of agents that function autonomously and interact with other agents within an environment. An agent is an encapsulated computer system that is situated in some environment and that is capable of flexible, autonomous actions in that environment in order to meet its design objectives. [17].

The flexible and autonomous character of agents can be explained as adaptive, an agent is capable of learning and taking his historical actions into consideration to optimize his own strategy. This immediately introduces two major drawbacks of agent-based systems in comparison to the more classical approach defined above:

- The patterns and the results of agent-based simulations are inherently unpredictable;
- Predicting the behavior of the overall system is extremely difficult because of the strong probability of emergent behavior.

The added value of ABM depends on how much is understood from the agent's behavior. An advantage is that ABM can rather easily be updated according to the latest available understandings about behaviors of the real world versions of the agents.

5.2 Design of agents representing human actors

5.2.1 Requirements

The restrictions on the agent who should represent human individuals, groups or nations, are essentially based on cognitive studies of human behavior. The basis for behavior is believed to follow Darwin's concept of optimization of intrinsic fitness. To achieve this, an agent needs to act within a complex world. From a Darwinian point of view, the acting of agents needs to follow a set of criteria in their activities, according to studies done to the development of a human behavioral model [18, 19], as follows:

- Sustainability: consumption of the resources which are physiologically essential for survival and avoidance of danger;
- Purposefulness: behavior is not fully random, but should follow criteria that relate to enhancing the sustainability of an agent;
- Actions need to be persistent and consistent to fulfill their purpose. The agent should also be able to interrupt his activities, temporary or permanent, when necessary;
- Finally, as concluded before, humans can learn. Therefore, an artificial agent representing a human agent must be able to learn to improve its purposefulness, sustainability and focus (improvement of the behavioral economics).

5.2.2 Drives

It is most likely that primary drives, those drives that are essential to an agent, are "hard-wired "; they are physically represented in the architecture of the human brain. There is scientific consensus on the following primary drives to be evolved in the brain, along the line of thought of Lieberman, Tooby and Cosmides as presented earlier:

- Get-food
- Get-water
- Avoid-danger
- Get-sleep
- Reproduce
- Higher level drives

It is argued in literature that there are also higher-level, hard-wired drives. In 1943, Maslov defined a need-hierarchy of relevant high-level drives [20]. As they might be of importance in a later stadium of this work, they shall be mentioned here: belongingness, esteem and self-actualization.

The relevance of these drives is variable and might strongly be influenced by, for example, cultural differences. They are all drives which are connected to social interaction and to a certain extend they are explainable from a Darwinian fitness point of view.

6. EXAMPLE

To illustrate the application of multi agent systems in an energy-strategy context, a model is presented which contains primitive foraging agents in a probabilistic world. The model is to verify in a simple way the hypothesis that the access to (non-food) exogenous energy can increase the probability of survival of individual agents. The model is written in Netlogo [21] and consists of a world divided into patches to which behaviors and values can be assigned; these patches can be considered as agents. In this world of patches live agents represented by turtles, which are, in contrary to the patches, mobile.

6.1 Agents

6.1.1 Resource agents

Patches are randomly assigned resources of food, also referred to here as endogenous energy. The resources have a probabilistic and cyclic character: the probability that a resource-patch actually contains a resource fluctuates with the seasons. This is modeled with a simple sinusoid function. Resource locations are fully random, no differences in resource concentrations are yet included, although this is more realistic given real world geographical differences. It would however be possible to import GIS-data about vegetation and soil fertility for example, to model real world situations. If a resource is harvested, it grows back slowly.

6.1.2 Foraging agents

The turtles represent the foraging agents. They live in groups with a home-basis. This assumption has an impact on the behavior of the turtles, in the sense that they always will return to the place which is considered to be their home. The turtles are driven by one of the primary lower drives "get-food" in a homeostatic way: a sort of thermometer monitors their need for food and controls the turtle’s decision to go out foraging. Turtles consume energy per step they make, as well as per unit time, so they have variable costs and fixed costs in time, whereas the variable costs are determined by the amount of labor they execute. In this model, the foraging agents are not learning. That means, that they do not remember where they encountered a resource at which time of year. If the agent remembers this, he could plan ahead and consider the economics of his foraging strategy by anticipating on the probability of emerging resources. Neural networks could be implemented for modeling the optimization of the foraging economics. The foraging agents have two incentives to return to their home-basis: after they have harvested a resource-patch and have reached their maximal endogenous energy level and an eventual surplus and at the end of the day when it gets dark and the foraging agents cannot see resource-patches.

6.2 Resources and socio-economic strategies

6.2.1 Exogenous and endogenous energy

The physiology of life is energy demanding, no endogenous energy or food simply means fatality or severe harm to the agent's fitness. From a physical fitness point of view it can therefore be expected that living species have evolved hard-wired drives that decrease the risk on fatality or decline in fitness. The application of exogenous energy resources seems to be a consequence of applied adaptive strategies, which extend the simple drive of decreasing the risk on lack of food.

6.2.2 Social strategy

In the example-model, the socio-economic strategy of the agents can be chosen to be either non-sharing (individualistic), or sharing (social). Sharing is that when a foraging agent returns at the home-base, the agent divides all the surplus of endogenous energy (food) the agents contains above the minimal energy level over the total number of agents that are member of his group. He keeps his own share and deposits the remains of the surplus at the central store, the home-basis. If due to poor conditions an agents returns home with his endogenous energy level below the minimum, he is allowed to consume energy from the central store to stay in healthy conditions, which means that the endogenous energy level is above the minimum.

6.3 A simple experiment

6.3.1 Setup of experiment

A simple experiment is designed to see the influence of exogenous energy on the intrinsic fitness of foraging agents. 5 different types of foraging agents are implemented, type number 1 to 5. With increasing type-numbers, the access to costless exogenous energy increases proportionally; taking into account that type number 1 does not have access to exogenous energy. This means that an agent of type 2 can carry out two times as much labor as an agent of type 1, at the same costs of endogenous energy; in other words, the wealth of the different agent types increases proportionally with their type-number. Agents of type 5 are therefore the wealthiest, agents of type 1 the poorest. The fact that the monetary costs of exogenous energy are not considered at this stage is justified as the current simple model only focuses on the hard-wired contents of fitness economics in the brain of a human being, and monetary valuation is assumed to represent cultivated adaptive behavior. Furthermore, the model does not take into account the negative side effects, which could influence the agent's strategy if he behaves adaptively.

In Figure 1, a screen shot of the Netlogo world is given after a sequence of time-steps. The North and South world edges are linked as well as the East and West edges. At each time-step, agents determine their situation and follow a sequence of rules to execute their following steps. They move randomly, increasing the distance from their home base when foraging and searching for resources. They find their way back home by following the "home-scent" of their own group. This means that there are as many scents on a patch available as there are groups of agents. When returning, a foraging agents ‘asks’ the patches surrounding him to return the intensity of the home scent of his group to him, on the basis of which the foraging agent decides which direction leads him back to his central store.

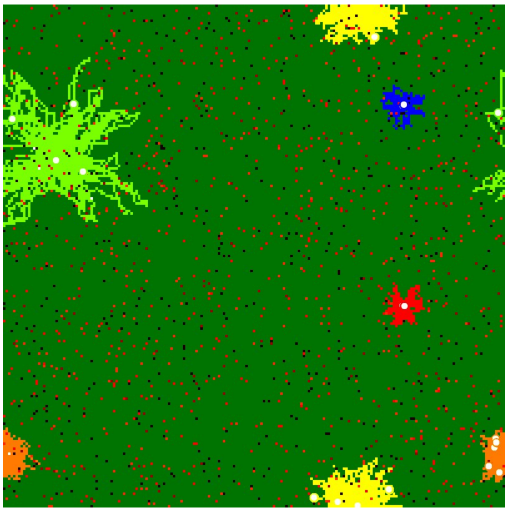

Figure 1: Mobile agents have been foraging for a sequence of time steps, leaving traces on patches where they passed by; at the centre of their traces is the actual home-base patch with the central store. Type 1 = red, Type 5 = green. The dark dots represent resources, their brightness indicating their extent. White spots represent the foraging agents.

The model has been run for both "social" and "individualistic" agents (see definitions in Section 6.2.2). During the runs, the average contained endogenous energy per group of agents was monitored. In case of the social model, the shared energy reserves in the central store were monitored as well.

6.3.2 Results

Simulations have been performed for social and individualistic agents. Agents of type 1 can not use exogenous energy ("poor agents"), agents of type 5 can carry out 5 times as much labor at the same cost of endogenous energy ("rich agents") and use exogenous energy to realize this increased amount of labor at the same endogenous energy costs. The exogenous energy is considered abundant and side effects of the exogenous energy use are not taken into account in this simple model. Simulations were run for both social and individualistic strategies. During these simulations, fitness in terms of contained energy per agent was monitored. In case of social strategy, reserves of endogenous energy (food) were monitored as well. Selected results are given in Figures 2-4 as a function of time (red line representing type 1, green line type 5 agents):

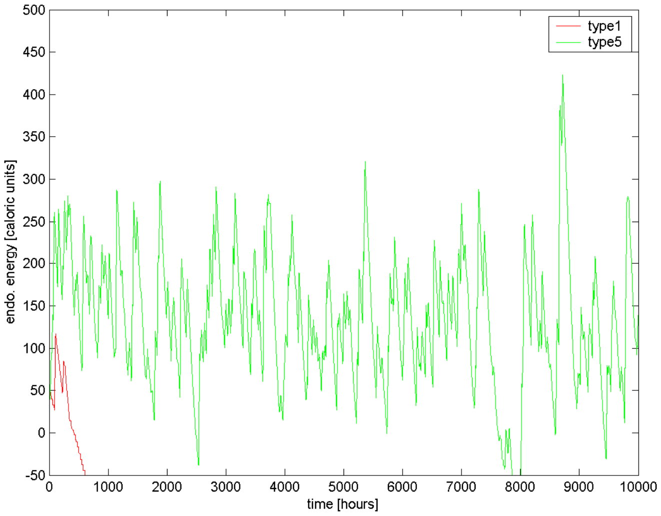

Figure 2: Average contained energy per type 1 and type 5 agents, if all agents follow an individualistic strategy.

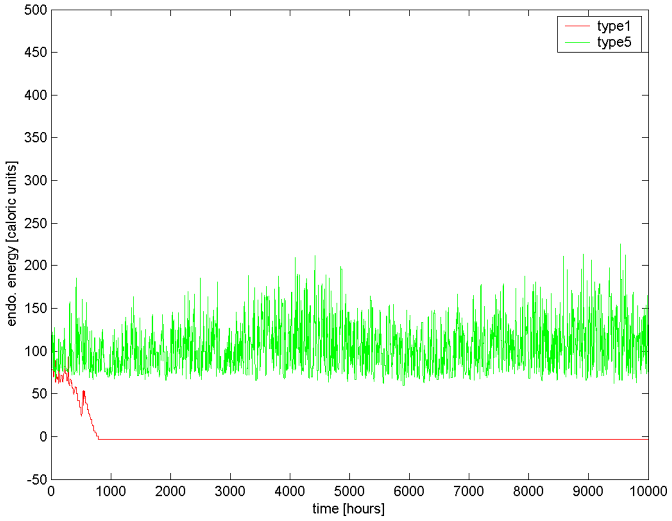

Figure 3: Average contained energy per type 1 and type 5 agents, if all agents follow a social strategy.

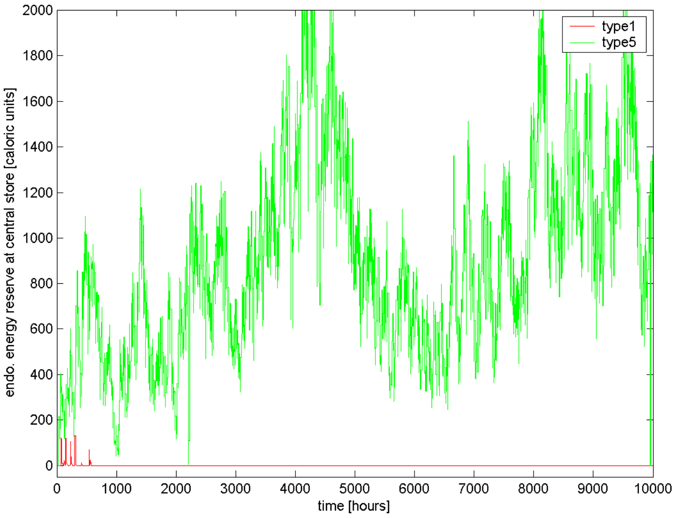

Figure 4: The food reserves at the central store of type 1 and type 5 agents, respectively.

6.3.3 Discussion of results

Although the current model is highly simplistic, it gives nevertheless already some idea on how an ABM approach could provide support to modeling of safety risks in future energy scenarios, such as in a possible future hydrogen economy.

Figure 2 shows that the moment at which the individualistic agents' energy becomes negative (which is the risk to be avoided) strongly depends on the "wealth" of an agent. While type 5 agents only very rarely face this risk (and always come back to positive values), type 1 agents experience "fatalities" due to this risk at a very early stage. The "critical wealth" in order to survive throughout the entire simulation period is at the level of type 4 agents.

Figure 3 gives clear evidence that cooperation is quite a successful risk avoiding strategy. However, this is again strongly linked to the agents' wealth in relation to the resource density in the world surrounding the agent: While for the resource density applied in the example, the social strategy does not pay-off enough for the poorest (type 1), it has a biasing effect on the risk profile for the wealthiest (type 5) and it is of critical importance for agents of "average wealth", e.g. type 4 agents, to follow a social strategy. The fact that type 1 "social agents" end up at constant zero energy values after long times and do not fall down to "fatal" negative values as their "individualistic" counterparts, is due to their programmed behavior to return to home base when fatally threatened, remain there and get food from their social partners (type 1 is both social and conservative).

Figure 4 shows another aspect of the sharing strategy: the food reserves at the central store, which remain largely positive for, type 5 agents. At some points, strong downward fluctuations can be observed: For type 5 agents the effect is negative, for agents of lower types, a visit of a type 5 agent always has a positive effect, as the type 5 agent deposes his surplus of food at the central store of the group in question. This shows that when agents of different type come too close to each other, they could influence each other's future pathways and thus have an impact on the entire behavior.

6.3.4 Discussion of the model

The ABM approach makes it fairly easy to model several aspects of a society without the need to have one single mathematical expression which addresses all the impact factors. Successful ABM application critically depends on the assumptions on behavior and social rules ruling this society. The added value compared to traditional prognostic approaches seems to be the easy adaptability and learning capacity of ABM models. For example, if the foraging agents are given a memory, they can remember the locations where they have found food before. They might learn to avoid these locations for a certain period as they have learned in between that it takes a resource time to re-grow. Neural networks provide an excellent tool to simulate this kind of learning behavior or pattern recognition and when implemented in agents the agents might learn to change strategies and to exchange knowledge and self-learned behavioral rules. The current model will be extended accordingly.

As a basis for a motivational system of the agents, a simple homeostatic regulator is applied which tells the agents to start searching for food when their systems run out of energy. In reality, however, it can often be observed that the more developed a society is, the more layers of cognitive rules will be applied by agents on top of the primitive homeostatic regulation rules in their interaction with other agents and the environment; complexity increases. Translating this to Maslow’s motivational hierarchy, it could be said that most developed societies are interacting in the highest level of Maslow’s motivational pyramid. Safety preferences of more developed cultures will also be more influenced by their level in the motivational pyramid. This is a qualitative explanation for the observation that socio-political risk discussions in higher developed nations often contain more subjective arguments, which, in times of economical crisis, often loose their relevance. Strictly economic models can not properly address economic crisis, while it can be expected that the search for food, fresh water and clean air will always go on, despite the economic conditions. Reference [15] showed differences in economic behavior among a variety of different cultures which can be explained to a large extend by the different training-paths the actors in the games had followed in their own specific culture. These training paths do not differ much from neural learning of agents that could be applied in a computational model. This would make subjectivity ‘objective’ in the form of a specific state of a neural network. Below this subjectivity, the primitive lower drives or motivations remain active, and constantly interact with the trained neural network. The result is that different cultures will have different approaches and valuations of risks. However, at the base the lower level motivational drives always remain active.

One of the assumptions made in the current version of the model, which is relevant in the energy safety context, is free availability of exogenous energy. The model so far does not consider the source of the exogenous energy nor does it consider political preferences of agent groups. Human reality is of course different, humans do not behave like primitive foragers who are blind for costs; contemporary western humans live in cultures which have fully adapted to monetary systems. Exogenous energy and specialized technologies are offered to users by specialized organizations in exchange of monetary units. End users will weigh the price of the exogenous energy to other expenses in life and will make a prioritization scheme, which helps him or her to decide whether the price for the energy is too high or not for the purpose it should serve. At the same time however, the end user will by all means want to avoid hazards. The problem here is, that the required specialized knowledge about an energy system is so specific, that the average public can not be expected to have expert judgment on the technological sophistication of safety systems. His or her experiences of safety concerns when switching to a new technology will much more depend on the trust he or she has in the energy-technology provider and this will not depend on the mathematical meaning of a complex numeric safety assessment prior to adopting the new technology. Therefore, reputation of the provider certainly plays a role in the decision made by the user to accept or not accept an offered alternative. The mathematical assessment plays an important communicative role, as it shows that the provider of a new technology is an expert in his field. But there is another phenomenon that seems to occur. When certain energy technologies are positioned high upstream in the supply chain, far away from the user, the safety-judgment of the user seems to change as well, since it becomes less visible to the user which of his or her “need” is actually fulfilled by that specific technology. More research should be done to the influence of this “technological interface thickness” on the judgment of hazards.

As much as the physical distance seems to play a role in the hazard judgment, time-span seems to play an important role in the safety judgment as well [23]. Hazardous events with direct effects on the user (detonation, fire, frost) are given the highest priority. More complex consequences of technology strategies, which are taking effect on a longer term, are typically given low priority. This could be a consequence of evolutionary stable human decision-making strategies, which at the end have evoluted into hard-wired programs in human behavior. Short-term hazard avoidance is essential: if you don't survive the short-term hazard, then it's not even worth taking the long-term hazard into consideration. According then to the evolutionary approach of Tooby and Cosmides [11], these kind of behavioral strategies would have developed in prehistoric times, during which population densities were low, resource variety was abundant and our ancestors behaved adaptive: moving to unexplored grounds (which could include adapting to new kinds of resources) after the exhaust of resources around the existing residence was an option, and thus short term strategies could pay off and were successfull. Western cultures focus on the stimulation and commercial exploitation of those similar primitive human behavioral systems within a protected, safe world and uses competitive stimulation as the source to power the economic engine. For those within the system, it has proven a successful peacekeeper after World War I and II and the cold war. Yet populations have grown dramatically and the materialized version of the western ideology requires more and more energy to keep the system running, as well as to keep it safe. It can be questioned what the effects are of cultural accepted preferences on the long term within artificially created environments in which agents are stimulated to behave according to motivations which were successful in a natural environment in which bounds weren't reached. Jared Diamond [24] provides arguments for the hypothesis that some of these contemporary cultural preferences and believes, combined with the globally connected societies which do not allow anymore to leave an exploited area in search of a greenfield, are intrinsically hazardous to the society itself. Although his examples of extinct small societies on bounded islands and areas are not fully comparable to today's globalized human world, both types of societies have to deal with a dependence of bounded resources and a lack of emigration valves.

In this context, hydrogen has the quality to spread the diversity of optional energy sources and thus spread the risk of lack of energy availability over more bounded resources. But at the same time, hydrogen could become an indirect threat as well since it will have to obtain its energy somewhere out of today's real time biosphere, whereas today's fossil fuels have absorbed there solar energy from the biosphere in over long periods in ancient times [25]. Although this doesn't necessarily pose a direct problem, the technological interfacing between the energy source and the end-user causes the latter not to experience direct negative consequences of exogenous energy use at all anymore; a hydrogen powered device only produces harmless water as a by-product, whereas the possible harmful effects have already occurred higher in the chain, invisible to the end user and his or her hard-wired behavioral survival subsystems. As long as wealth is hold on to as the leading parameter to express competitiveness and status (whether hard-wired or not), global competition will automatically lead to more energy use since wealth is closely related to energy consumption. The global competition is now powered with fossil fuels that have consequences for global climate changes, but it doesn't put a large burden on the earth's surface in terms of surface coverage by energy conversion systems (single crop biomass, windmills, fields of pv-systems, etc.). ABM provides the means to address and simulate these kind of hazard shifts. Diamond provides evidence for the theory, substantiated with historical examples, that cultural strategies, defined in terms of for example social principles as status and belief, can have a blinding effect and overrule the biological, Darwinian survival strategies, with hazardous if not fatal consequences. This intrinsic hazard can not be ignored when judging on safety consequences of technological choices which are following ones' own cultural preferences, ABM allows to take preferences and believes into account and to look at the long term effects of these phenomena from a "helicopter-view".

7. CONCLUSIONS

From this initial study, it can be concluded that a multi-agent approach to modeling of safety risks in energy scenarios is a promising new approach to learn about emergent socio-political trends that might critically affect the development and acceptance of new technologies. Differences versus traditional prognostic approaches have been discussed: For analyzing conceptually new technologies that are widespread and tightly connected, the traditional approaches are too rigidly defined and often do not sufficiently well address the complex economical, social or biological interactions of living species [22]. The number of possible combinations of existing pieces of knowledge, new technologies and social strategies is endless and is a multidimensional space in which decision-making agents constantly look for an optimum in terms of fitness, but in which cultural deformations cause deviating pathways. Reducing risks to agents' access to fitness in one dimension might increase the same risks in other dimensions. ABM could help to identify the changes in risks as a consequence of changing strategies and beliefs of the decision-making agents. However, parameters that agents can take into consideration should be chosen very carefully in order to keep computational costs for resulting models within reasonable limits.

8. FUTURE WORK

In order to become a functional decision support tool addressing hydrogen risk scenarios, the current simple model described in this paper needs to be extended in the above-mentioned ways. In addition, a proper interface to existing data on hydrogen technologies and their consequences in terms of safety risks has to be developed. Since hydrogen is not an energy source but an energy carrier, hydrogen risks should also include risks, which are a consequence of the energy production chain used to support a hydrogen economy. Furthermore, as hydrogen is not the only candidate for future energy technologies, other technologies need to be considered in the model as well in order to allow fair comparisons. Work in progress.

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