Jul 13th, 11:50 AM - 12:10 PM

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International Environmental Modelling and Software Society (iEMSs)
8th International Congress on Environmental Modelling and Software
Toulouse, France, Sabine Sauvage, José-Miguel Sánchez-Pérez, Andrea Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2016-proceedings

Actor-Based System Dynamics Modelling of Win-Win Climate Mitigation Options

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Abstract: The actor-based system dynamics approach to Integrated Assessment modelling (IAM), seen as further development of 'traditional' system dynamics economic modelling, however with a stronger emphasis on describing the decision making of key aggregate economics actors, is a promising methodology for developing the comprehensive IAMs of next generations. The present paper is focused on application of actor-based system dynamics models to identification and assessment of win-win opportunities of climate mitigation policies. Modelling results outlined suggest that in a multi-country world properly designed climate mitigation policies can unite rather than divide different nations, therefore putting under question the 'juggernaut' of much discussed free-rider problem, and reframing the climate mitigation problem into a positive forerunner perspective. At the same time, improperly designed policies might pose serious obstacles to climate forerunners. Trade and climate/environment conflicts (particularly related to Chinese solar panels) are discussed as recent negative real-world examples of this kind. A stylized 'solar panel conflict' model developed within actor-based system dynamics modelling approach is presented to simulate the dynamics of production under alternative scenarios of conflict resolution. Preliminary modelling results provided suggest that protectionist measures adopted in real-world trade and environment conflicts are not the best solutions even from 'pragmatic' viewpoint of protecting the domestic producers from 'competitive disadvantage', to say nothing about reaching the climate/environmental protection targets.

***Keywords**:* climate mitigation; Integrated Assessment; system dynamics; trade and environment conflict; win-win solution.

1 INTRODUCTION

In a recent comprehensive review of historical development of Integrated Assessment models (IAMs) Farmer et al. (2015) suggest that in the next generations of IAMs '…many existing methodologies from social and physical sciences need to be deployed, and new modelling techniques and ideas still need to be developed'.[1] In particular, the authors of the cited paper discuss in detail two modelling methodologies as promising candidates for further advancing the IAMs – namely, the dynamic stochastic general equilibrium (DSGE) models and the agent based models (ABM).[2] Farmer et al. (2015) coined the term *agent-based integrated assessment models* (ABIAMs) for one of emerging classes of climate-economic models, and referred to one of the models developed by the authors of the present paper and described in (Hasselmann and Kovalevsky, 2013) as to a member of the class of ABIAMs.

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[1] (Farmer et al., 2015, p. 329).
[2] Regarding ABM and their applications to climate and environmental economics, see e.g. (Farmer and Foley, 2009; Filatova et al., 2011; Wolf et al., 2013).

Indeed, the proper description of behaviour and decision making of economic agents/actors is undoubtedly crucial for successful development of future generations of IAMs. ABM (that normally describe very large populations of agents) might be seen as one of the promising paradigms in this respect. At the same time, the authors of the present paper firmly believe that efficient tools for adequate description of actor behaviour might be alternatively (or complementarily) borrowed from the domain of system dynamics (SD). The SD approach, pioneered by Jay W. Forrester in 1950s (Forrester, 1971), nowadays has a track record of fruitful applications to problems of environmental economics and – later – of economics of climate change, starting from the influential World3 model described in *'The Limits to Growth'* (Meadows et al., 2004), and followed by a number of other SD models developed by Fiddaman (2002), Hallegatte and Ghil (2008), Hallegatte et al. (2008), Kellie-Smith and Cox (2011), Sterman (2000), Sterman et al. (2011), Walsh et al. (2015) and other authors.

The authors of the present paper, in co-operation with their colleagues, are developing what they call the *actor-based system dynamics approach* to Integrated Assessment modelling, which, in brief, might be seen as further development of 'traditional' SD economic modelling, however with a much stronger focus on describing the behaviour and decision making of key aggregate actors of economic system. The distinctive features of actor-based system dynamics modelling approach are discussed in detail elsewhere (Hasselmann et al., 2015; Hasselmann and Kovalevsky, 2013; Kovalevsky and Hasselmann, 2014a; Weber et al., 2005), including the paper presented at the previous iEMSs 2014 Congress (Kovalevsky and Hasselmann, 2014b). A system of models developed within the actor-based system dynamics approach, known also as the MADIAMS model family, is described and presented in detail at a dedicated MADIAMS homepage maintained at the Global Climate Forum website[3] (Barth, 2003; Hasselmann and Voinov, 2011; see the full list of publications on MADIAMS model family at the above mentioned MADIAMS homepage).

In the present paper the question of reframing climate mitigation problem in terms of win-win opportunities, including the ways for resolution of the so-called 'trade and environment' conflicts, is tackled and illustrated by new actor-based system dynamics models – representatives of the MADIAMS model family.

2 MODELLING THE WIN-WIN OPPORTUNITIES OF CLIMATE MITIGATION POLICIES

The limited success achieved so far in the area of global climate agreements has been extensively discussed by many authors in the 'free-rider problem' framework. According to this framework, climate mitigation can be achieved only through joint actions of all countries. Any single country – even a large greenhouse gases (GHG) emitter – would not significantly mitigate the climate change if it acts alone. According to the mainstream viewpoint, such a country would bear net economic losses, while countries not participating in climate agreements ('free-riders') would benefit for free from climate mitigation actions of participating countries. This free-riding in climate negotiations leaves little incentive for climate mitigation policies.

As recently suggested by Hasselmann et al. (2015), climate mitigation policies at the regional level, if well designed, could be beneficial for the countries initiating them, therefore eliminating the free-rider motivation for inaction, creating instead incentives to forerunning. This reframing of climate mitigation problem from a free-rider to a forerunner perspective is supported by actor-based system dynamics economic models which go beyond measuring the well-being of a country solely in GDP terms and incorporate also other measures of well-being (notably the employment level) in the modelling framework.

As example, the North-South Euro crisis model was developed by Hasselmann et al. (2015) along these lines, suggesting that properly designed climate mitigation actions might help the resolution of the euro crisis.[4] Modelling results indicate that purpose-oriented green investment (e.g. in renewable

[3] http://www.globalclimateforum.org/madiams. MADIAMS is an acronym for a Multi-Actor Dynamic Integrated Assessment Model System.
[4] The North-South Euro crisis model presented in (Hasselmann et al., 2015) is described in detail in the *Supplementary information* accompanying the cited paper (http://www.nature.com/ngeo/journal/v8/n12/extref/ngeo2593-s1.pdf, open access). The model itself

energy production) from North to South (the latter experiencing the budget deficit) might help resolve the euro crisis with substantially smaller decrease in the employment level in the South (as compared with the traditional – and actually adopted – austerity scenarios).

Therefore, *properly* designed climate mitigation policies might unite rather then divide nations, creating incentives to forerunning in climate mitigation. However, the controversy presented in the next section clearly demonstrates that, on the opposite, *improperly* designed policy measures (no matter by what 'good intentions' they are justified) might be painful for climate mitigation forerunners.

3 TRADE AND CLIMATE/ENVIRONMENT CONFLICTS

As pointed out by Wu and Salzman (2014) in their recent in-depth analysis of legal issues related to trade and environment conflicts, tensions between international trade and environmental protection are not new. Indeed, encouragement of national climate/environmental policies and removal of protectionist trade barriers are seemingly two competing goals of global governance, and finding win-win solutions to resolve this controversy does not look like a simple task.

However, in an overview of the history of trade and environment conflicts Wu and Salzman (2014) reveal the recent 'regime shift' in the essence of such conflicts.

Earlier 'Classic' cases of 1990s (in the terminology of the cited paper) might be viewed from the perspective of North–South division. A common narrative of these cases is that rich developed countries enacted domestic environmental policies (e.g. in fisheries), but at the same time did not want to place their domestic producers at a competitive disadvantage. Therefore, protectionist measures were taken, e.g. banning imported products from poor exporting countries that did not meet the similar environmental standards. Wu and Salzman (2014) notice that this 'Classic' argument has later become again a subject of hot debates with respect to climate mitigation problem (in the form of discussions on border restrictions against international competitors not adopting carbon emission reduction measures).

A new series of trade and environment conflicts (called in the cited paper the 'Next Generation' trade and environment conflicts) that intensified in 2012 after a relatively calm decade and lasts until now, is fundamentally different. These conflicts can no longer be portrayed by a conventional North–South dichotomy. In the 'Next Generation' conflicts both sides (developed and developing countries) are adopting green industrial policies beneficial for climate/environment, but questioned by many from the viewpoint of international trade rules.

The present paper is devoted to probably the most visible trade and climate/environment conflict of recent years related to Chinese solar panels.[5]

The story started in 2011 when a group of several US solar panel producers accused Chinese solar panel manufacturers of dumping products in the US. As a result of investigation, anti-dumping tariffs ranging from 24% to 36% were imposed on Chinese producers (GPEC, 2012; Lester and Watson, 2013).

The story then continued in Europe.[6] A complaint of some European producers against Chinese solar panels, cells, and wafers, claiming that these products are being dumped in the EU market, led to the largest anti-dumping investigation by value in history,[7] that, in its turn, led to imposition by the EU of two different protectionist instruments simultaneously: anti-dumping and anti-subsidy duties (EC,

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coded in Vensim is available for free download at the MADIAMS homepage maintained at the Global Climate Forum website (http://www.globalclimateforum.org/madiams).

[5] A number of other recent examples of trade and climate/environment conflicts is described by Lester and Watson (2013), and by Wu and Salzman (2014).

[6] A very informative summary of EU–China trade dispute is provided by Yu Chen (2015).

[7] In 2011 solar panels constituted 6.5% of China's export to Europe, amounting up to about $27 billion (Lester and Watson, 2013).

2016).[8] In response, China decided to launch an anti-dumping and anti-subsidy probe against some goods imported from the EU.

Fortunately, given the mutual importance of bilateral trade between the EU and China, this solar panel conflict did not escalate into a trade war; instead, the trade dispute was settled. Given the growing bargaining power of China, the obvious conflict of interests between solar panel consumers and manufacturers, and also the divergent perception of the situation within the EU itself (some influential EU Member States with large volumes of trade with China were in fact against imposition of protectionist measures), the settlement reached as a result of EU-China trade dispute was less painful for Chinese manufacturers than initially imposed measures (Yu Chen, 2015).

In the next section a stylized model of 'solar panel conflict' developed within the actor-based system dynamics approach is presented, and alternative scenarios of resolution of conflicts of such kind are explored.

4 MODELLING THE SCENARIOS OF 'SOLAR PANEL CONFLICT' RESOLUTION

A Vensim[9] sketch of a stylized 'solar panel conflict' actor-based system dynamics model is presented in Figure 1.[10] The model world consists of two regions, referred to simply as China and the West. Shown are the impact of Chinese solar-panel production, represented by the state (box) variable **CfirmSP,** on the production of western solar energy systems, represented by the remaining four box variables: **firmSP** (capital value of firms producing solar panels), **solar panels** (value of installed solar panels) **firmES** (capital value of firms producing solar energy systems**),** and **energy systems** (value of installed solar energy systems). The evolution of the system is influenced by Chinese and Western state subsidies (**subC** and **subW**, respectively).

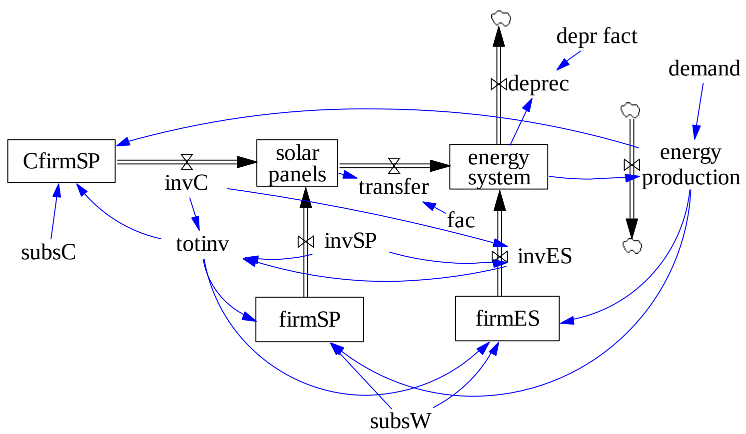

Figure 1. A Vensim sketch of the 'solar panel conflict' actor-based system dynamics model.
Explanation of some state (box) variables:
CfirmSP – physical capital of (aggregate) Chinese solar panel firm;
firmSP – physical capital of (aggregate) Western solar panel firm;
firmES – physical capital of (aggregate) Western energy system firm.
See further details in the paper text.

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[8] After the US and the EU, Canada imposed tariffs on imported Chinese solar equipment in 2015 as well. Australia also claimed that China was dumping solar panels at the Australian market; however, no duties were imposed (Yu Chen, 2015).
[9] The Vensim software is developed by Ventana Systems, Inc. (http://vensim.com/).
[10] The Vensim model described in the present paper is available from the authors upon request.

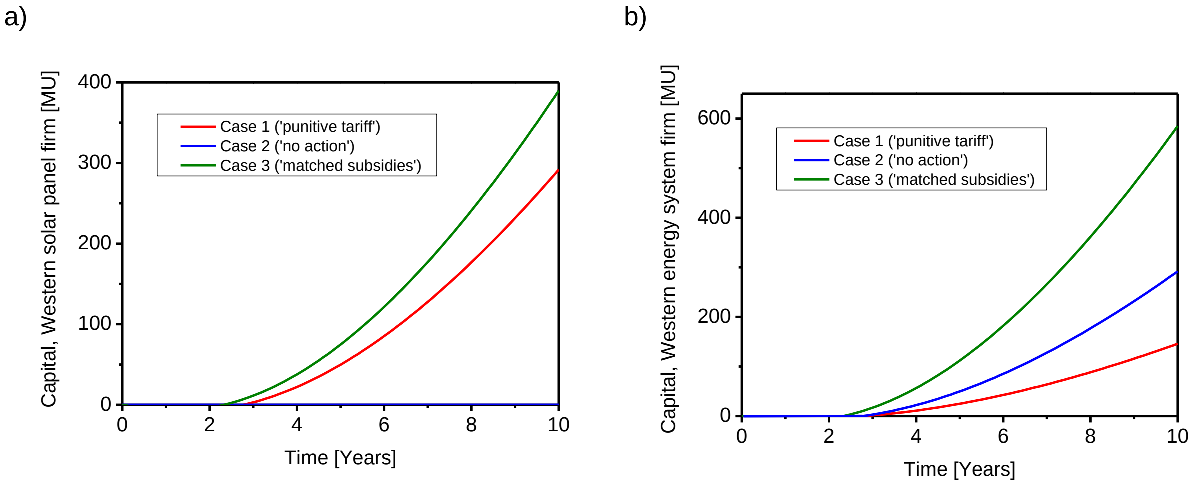

Figure 2. The dynamics of variables a) **firmSP** (capital of Western solar panel firm) and b) **firmES** (capital of Western energy system firm) for three alternative scenarios:
red line – Case 1 ('punitive tariff');
blue line – Case 2 ('no action');
olive line – Case 3 ('matched subsidies').
See the explanation of scenarios in the paper text.

We consider the situation when the Chinese solar panel producer is supported by domestic subsidies, and explore three alternative scenarios:

- Case 1 ('punitive tariff') – punitive tariffs are imposed by the West on Chinese solar panel producers, that corresponds to the actual recent conflicts described in the previous section;
- Case 2 ('no action') – the West accepts Chinese subsidy as permissible and consistent with the policy of independent national contributions to two-degree global climate mitigation target;
- Case 3 ('matched subsidies') – the potentially negative direct economic impacts of Chinese subsidies on Western solar panel producers are neutralized through matched subsidies (i.e. through parallel increase of Western solar-panel subsidies).

The short-term dynamics of physical capital of the Western solar panel producer (**firmSP**) and of the Western conventional energy producer (**firmES**) under three scenarios outlined above is shown in Figure 2, a) and b) respectively.[11] In Case 2 ('no action') the Western solar panel industry is uncompetitive and dies out. In Case 1 ('punitive tariff') the Western solar panel industry is growing; however, the Western energy system performs worse than in Case 2. And, finally, in Case 3 ('matched subsidies') both the Western solar panel industry and the Western energy system experience the most rapid growth among the three considered scenarios.

5 CONCLUSIONS

With application to trade and climate/environment conflicts, the modelling results reported in the previous section suggest that protectionist measures against foreign subsidized environmental technology, as described in Sec. 3, are clearly not the best solution – even for the performance of the domestic industry striving to achieve a green transformation. While domestic solar panel makers suffer from subsidized foreign solar panel imports, the domestic renewable energy sector as whole profits from the availability of cheap solar panels. Seen from the common goal of protecting the global climate, the optimal response to foreign solar panel subsidies is to match foreign subsidies by similarly increased domestic subsidies, thereby opening a positive trade alliance rather than a trade war against the destruction of our planet.

[11] The model is currently not calibrated yet; monetary units [MU] on Figure 2 are arbitrary.

The model outlined in the previous section is very simple. Elaboration of the more detailed models of resolution of trade and climate/environment conflicts will imply, among other things, explicit inclusion of the conflict of interests of solar panel consumers and manufacturers in the modelling scheme, calculation of emissions and coupling the economic module with the climate module. These tasks are left for further research.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Community's Seventh Framework Programme under Grant Agreement No. 308601 (COMPLEX).

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