Dynamics of the European demand for lignocellulosic (2G) ethanol:

An analysis of policy and learning effects on market growth

Djerdj Horvat*, Christian Lerch*, Sven Wydra*

* Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Str. 48
76139 Karlsruhe, Germany
Phone: +49/721 6809-371

Email: djerdj.horvat@isi.fraunhofer.de

A key approach to progress along the path to further sustainable development is the continuous switch to second generation biofuels, which are derived from non-food resources. One of the most promising biofuels is lignocellulosic (2G) ethanol. Nevertheless, due to the current absence of cost competiveness, the 2G ethanol market is strongly dependent on policy support. Moreover, the production costs for 2G ethanol play a crucial role for future cost competitiveness and thereby for market development. Hence, the key question that arises is how the linkage between the policy-induced market growth and the reduction of production costs can influence the dynamics for 2G ethanol demand. To examine these dynamics and interaction in Europe over a forecasted 20 year period, a simple System Dynamics model was developed as a part of a research project funded by the European Union. The results of simulation runs show a positive impact of learning effects resulting from build up and running of new capacities on 2G ethanol price and thereby on 2G ethanol market demand. Moreover, it has been proven that these effects are closely interlinked with the considered policy incentives in the form of quota regulations according the Renewable Energy Directive (RED II).

System Dynamics, lignocellulosic (2G) ethanol, quota regulations, learning effects

1. Introduction

Currently biofuels contributed significantly to goals for renewable energy and ambitious greenhouse gas emission reduction targets in Europe. But, first generation biofuels have also been highly criticized because of food vs. fuel debates because of direct and indirect change in land use (LUC and ILUC). Moreover, biofuel's sustainability qualities have been disputed (Timilsina/ Shrestha A. 2010). A key approach to the path to more sustainability development is the continuous switch to second generation biofuels, which are derived from non-food resources. One second generation biofuel is cellulosic ethanol that may be produced from agricultural residues (e.g. straw and corn stover), other lignocellulosic raw materials (e.g. wood chips) or energy crops (miscanthus, switchgrass, etc.) (EPure 2016).

Today, the global production of second generation (2G) ethanol is still very low, but increasing, as several new 2G facilities have become operational in the last 3 years (Bio-Tic 2015b; UNCTAD 2015). One full commercial plant is operative in the EU (Beta Renewables in Italy), which accounts for somewhat less than 1% of the overall ethanol production capacity in Europe (Philips et al. 2016). Still, significant technological challenges in the build up of commercial plants occur. In particular, cost competitiveness compared to 1G generation biofuels and fossil fuels has not been achieved yet, as some production steps (e.g. pre-treatment of cellulosic), are still not optimized.

Because of absence of cost competiveness, the lignocellulosic bioethanol market is strongly dependent on policy support, mainly on quota obligations for biofuels (Bio-Tic 2015). In 2015, the European Commission (EC) amended the Renewable Energy Directive and officially introduced a seven percent cap (=share of biofuels in total fuels) on food based biofuels thus limiting future production of these first generation biofuels, and introduced an indicative, non-binding 0.5% sub-target for second-generation of biofuels (double counted towards the 10% renewable target in transport). However, these indicative targets have not led to a strong market pull yet. At the end of 2016, the European Commission published a proposal for a new Renewable Energy Directive (RED II), where an obligation of 3.6 % for 2G generation biofuels is envisaged. Currently, uncertainties regarding future regulations still exist and so does the outlook for second generation lignocellulosic ethanol in Europe (see e.g. OECD/FAO 2016; BioTic 2015; Hirschnitz-Garbers/Gosens (2015).

Even without reaching full cost competitiveness the production cost for lignocellulosic ethanol will have an important role for market development, as it is more likely that envisaged quotas will be actually transferred into national regulation and fulfilled or slightly overachieved in reality. Once again, production costs are highly dependent on the potential (policy-induced) market size. A significant amount of literature has studied potential costs reduction from scale and learning effects and assumes significant reductions. This in turn may lead to convergence compared to 1G biofuels and fossil fuels in around roughly 15-20 years (e.g. IEA-ESTAP, IRENA 2013; Daugaard et al. 2014; Festel et al. 2015; Jonker et al. 2015).

For an analysis of that convergence, a System Dynamics model is well suited (Vimmerstedt et al. 2012; Barisa et al. 2015). Therefore, a System Dynamics model could be developed which aims to analyze the following research question:

- *How does the linkage between the policy-induced market growth and the reduction in production costs resulting from learning effects influence the dynamics of demand for 2G ethanol in Europe?*

To analyze the dynamics of 2G ethanol demand based on interactions of policy incentives and learning effects as result of production capacity changes, a System Dynamics model was constructed for the ethanol value chain. The model represents work in progress in a research project funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 723687.

The paper is organized as follows. First, a short literature analysis was conducted to identify the interactive effects of policy-incentives and learning effects on demand. The findings are used in section 2 to construct a model containing stock and flows which forms the basis of the System Dynamics model. Following that, in section 3 simulation runs and tests are conducted to analyze the impacts of individual factors and to obtain first insights into the system's behaviour. The last section looks at conclusions which can be drawn from these findings.

2. Policy-incentive and learning effects on 2G generation ethanol demand

To develop a system structure which links policy-incentives and learning effects on 2G ethanol demand, we built a simulation model with three subsystems. The subsystems are interacting with each other via the key variables – "2G ethanol demand", "process costs" and "price change". Figure 1 depicts a simplified structure of the System Dynamics model with its three subsystems.

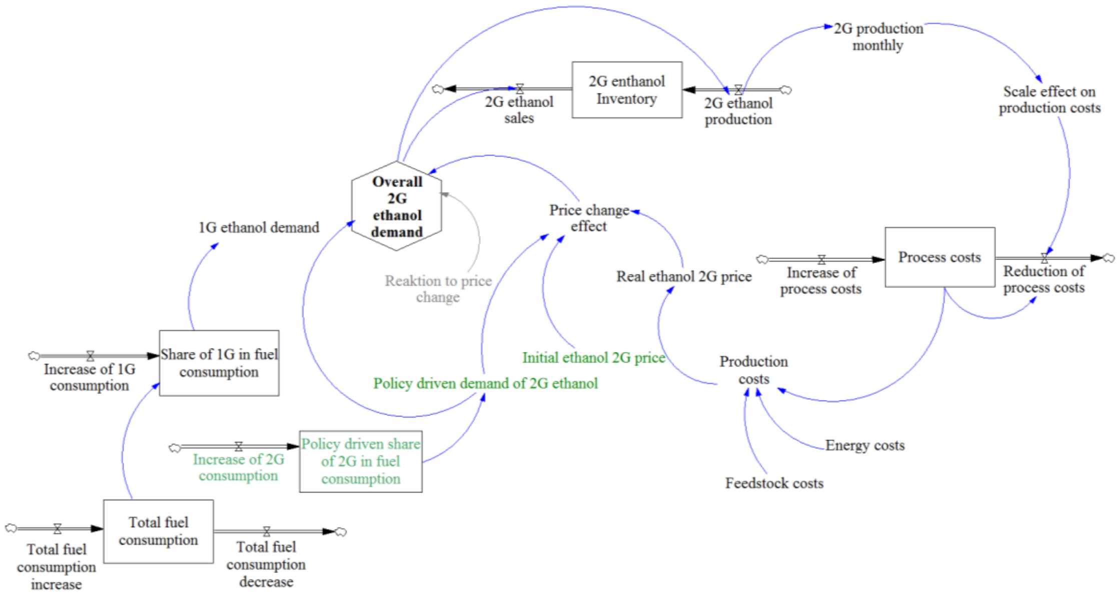

Figure 1: The simplified structure of the SD-model with three subsystems

The first subsystem (see figure 1) represents the initial demand of 2G ethanol which is derived from the initial total fuel consumption based on the indicative targets presented in the following table 1 (EC, 2016).

Year	2010	2015	2020	2025	2030
% of the total fuel con-sumption	0.01	0.11	0.25	0.45	0.5

Table 1: Indicative targets for 2G generation ethanol in Europe

As the production costs, and thereby the price for 2G generation ethanol, depend on the potential (policy-induced) market size, we use the initial demand for 2G ethanol as a starting point for the second subsystem, reflecting the demand on production capacities (see figure 2). Furthermore, with increased production capacities, the process costs of the ethanol production decrease.

The reason for this cost reduction is dynamic learning effects via technological process. Learning effects have been discussed intensively for biomass-based innovations such as lignocellulosic ethanol because of their rather low technological maturity compared to established oil-based products (Ye et al. 2014; Festel et al. 2014). Potential aspects for improvement regarding the production of lignocellulosic ethanol relate to a more efficient organization of production and transportation processes, the use of advanced materials, lower costs of the enzymes for pre-treatment processes and lifetime prolongation of catalysts (de Wit et al. 2010). Techno-economic literature for biomass technologies has commonly accepted the experience curve approach to estimate the aggregated effect of technological learning over future time periods. According to this concept, costs decline by a fixed percentage amount with each doubling in cumulative production (De Wit et al. 2010; Festel et al. 2014).

A noteworthy amount of literature has studied potential costs reduction from scale and learning effects and assumes significant reductions, which may lead to convergence compared to 1G biofuels and fossil fuels in around roughly 15-20 years (e.g. IEA-ESTAP, IRENA 2013; Daugaard et al. 2014; Festel et al. 2015; Jonker et al. 2015). For modelling the learning effects, we calculated scaling effects (from 1% to 10%) in accordance with the multiplication of the production capacities compared to the start demand - from 1 time to 100 times. Because we started with a very low level of demand at the initial time (2010), and this amount increases rapidly (e.g. IEA-ESTAP, IRENA 2013; Daugaard et al. 2014; Festel et al. 2015; Jonker et al. 2015), we use low scale effects (1%) for multiplications of up to 7 times. A delay of 6 months is also integrated into the model, which indicates the time for real reduction of prices after a scale effect occurs.

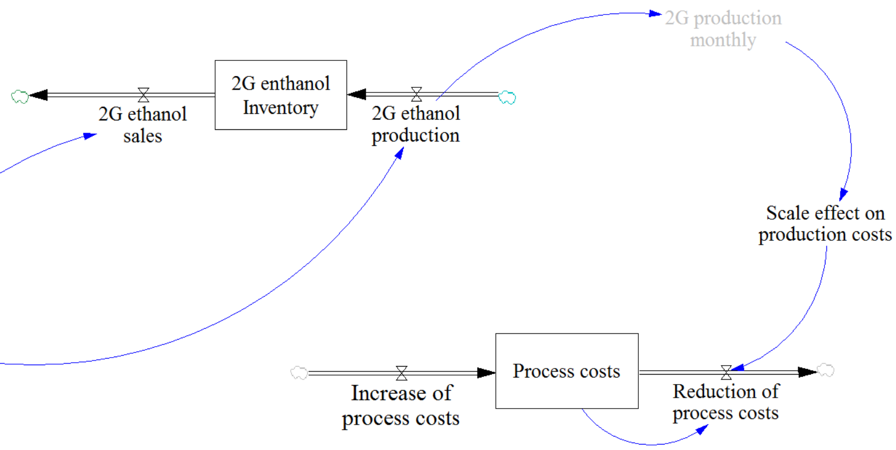

Figure 2: Effect of 2G ethanol market price on demand

In the third subsystem we modelled the effect of changed production costs on 2G ethanol demand (see figure 3). Following the study of IEA-ESTAP and IRENA (2013) we calculated production costs as a sum of process costs (42%), energy costs (16%) and feedstock costs (42%). To simplify the model considering only the effects of process costs on real price and demand, we calculate production costs as individual variable of the real 2G ethanol price.

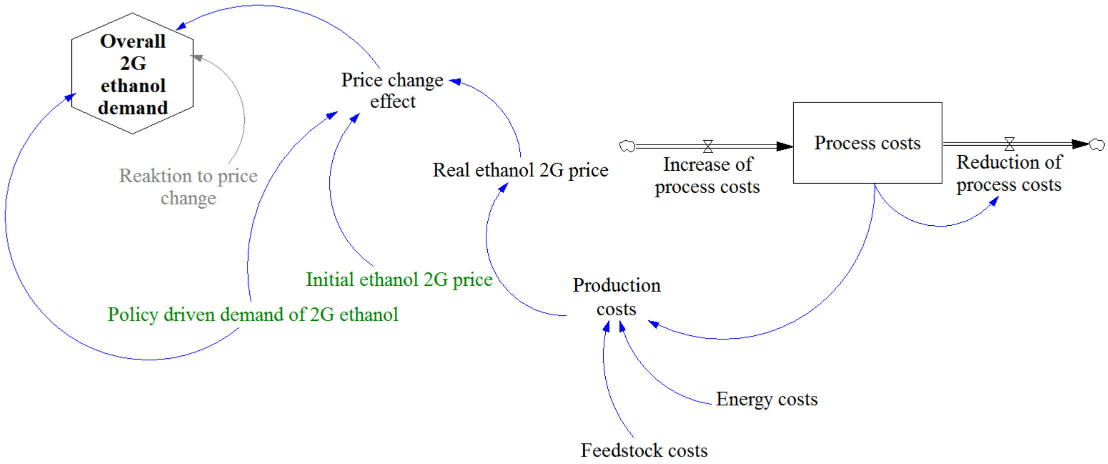

Figure 3: Effect of changed production costs on ethanol 2G price and overall demand

Assuming price elasticity = 1, the model calculates the change of the 2G demand based on the difference between the initial and the calculated real price as result of the decreased process costs. As the customers do not simultaneously react to price changes, a delay of two months is integrated in the model to capture this effect.

3. First results of the ethanol demand dynamics

After validation tests of our System Dynamics model, in which we verified the structure of the model and validate it through extreme conditions experiments and sensitivity tests, the model is ready for first system behaviour analysis for policy making. For a dynamic analysis and a deeper understanding of the system's behaviour, various simulation runs and tests were conducted. Some exemplary runs are shown in the following and interpreted to generate the first dynamic hypotheses.

Figure 4 shows the dynamics of the 1G (Line 1) and 2G (Line 2) ethanol demand in the time period of 240 Months starting from January 2010. For the 2G ethanol we simulate under the assumption of an indicative target – following the Renewable Energy Directive (RED II) - that the share of 2G in total fuel consumption in 2030 will be 0.5%.

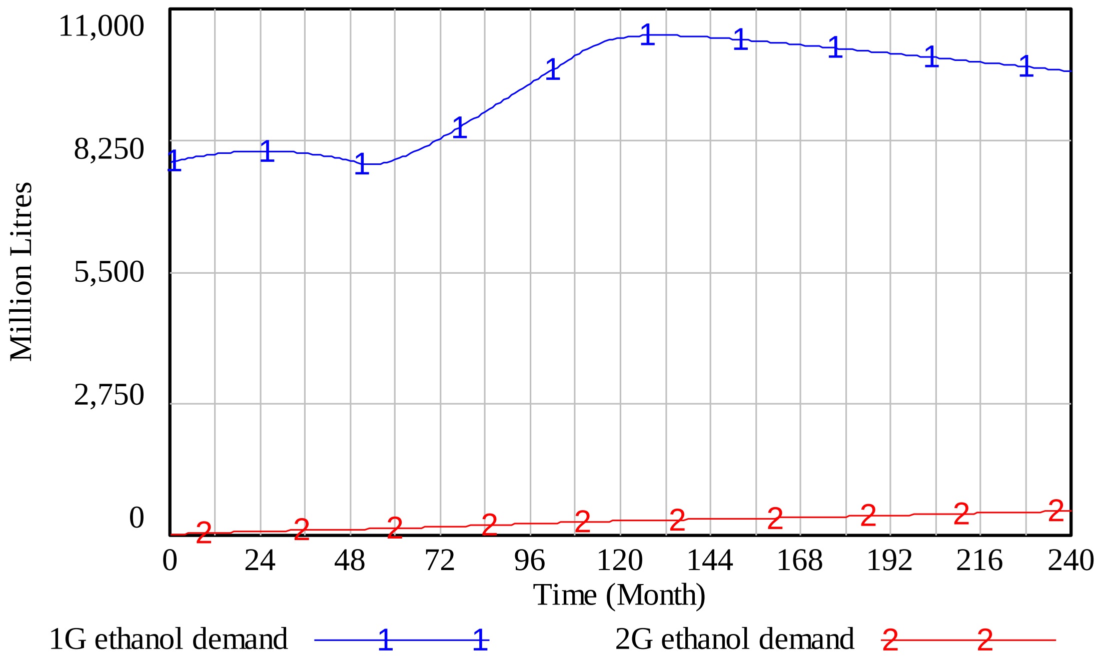

Figure 4: 1G and 2G ethanol demand between 2010 and 2030[1]

The runs in figure 4 show 1G ethanol demand increases between 2015 and 2020, up to a level of approximately 10.500 million litres. This boost results from a higher share of 1G ethanol of the total fuel consumption in 2015, switching from 4% to 6%. After reaching its peak in the year of 2020, the 1G demand slowly decreases again, because the share remains the same, but the total fuel demand decreases from 2020 until 2030. Moreover, at around 2025 the 2G demand starts to increase slowly, reaching a level of 600 million litres in 2030. This derives from boosting the share of 2G ethanol from 0.25% in 2020 to 0.45% in 2025 and hence, it is almost doubled (compare tab. 1). But due to this very slow increase it seems necessary to generate further simulation runs, showing the potential effects resulting from an additional initial share.

[1] By policy-driven share of the 2G ethanol demand 0.5 % of the total fuel consumption (Base run)

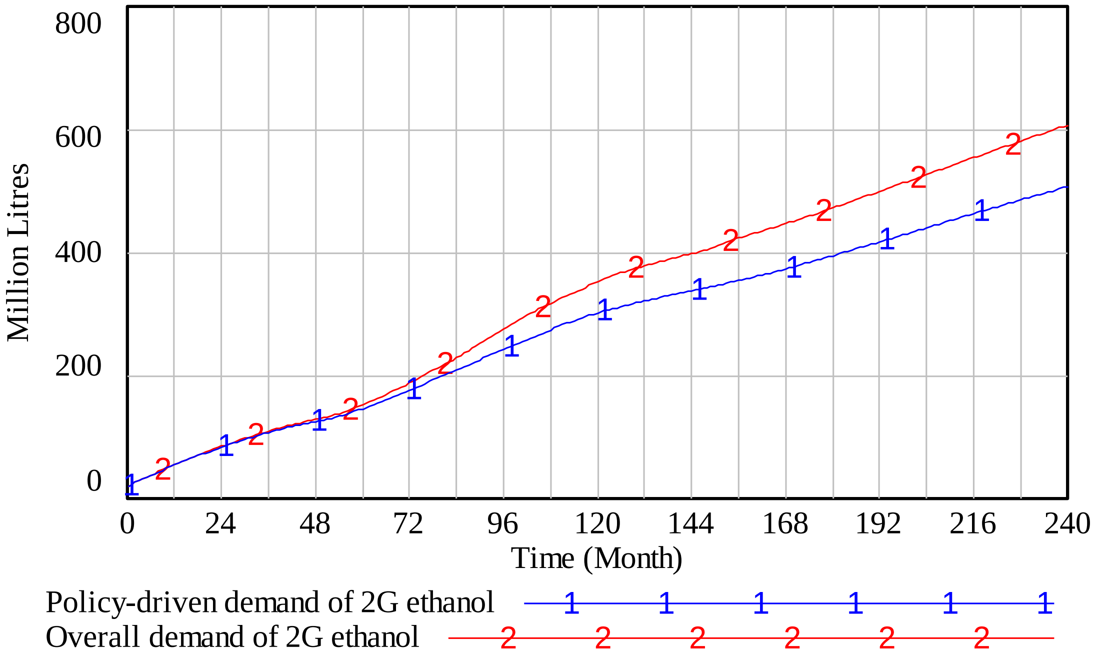

Figure 5: 2G ethanol demand by policy-driven share in total fuel consumption 0.5 % in 2030 (Base run)

In order to gain a deeper insight into the dynamic behaviour of the 2G ethanol market and its interactive links to learning effects and policy incentives, we analyzed various demand scenarios for Europe. Therefore we modified the share of 2G ethanol in 2030 from 0.5% to 3.6 % and compared the policy-driven demand and the overall demand of 2G ethanol. The policy-driven demand describes the amount of litres generated by the legal share of 2G ethanol of the total fuel demand. In contrast, the overall demand includes the legal share plus the additional consumption of 2G ethanol. While the policy-driven demand is given by law, the additional demand depends on the market price. Consequently, the higher the learning rate, the lower the market price and hence, the higher the overall demand. This demonstrates how the legal share affects an impact on the overall demand, too. The following figures show the dynamics of the 2G ethanol demand, as the result of policy incentives, and the overall 2G ethanol demand, as the result of learning effects resulting in an additional 2G ethanol demand.

Figure 5 represents the base run in which an initial share of 2G ethanol in total fuel consumption of 0.5 % was used. As the graph illustrates, the “Overall Demand” (line 2) is growing faster than the “Policy-driven Demand” from 2016. In 2030 it reaches a demand capacity of approximately 600 million litres and hence, almost 100 million litres more than the initial demand. Moreover we observe the “gap” between real demand and initial demand is opening over time. These effects result from an accelerated price decrease, leading to a faster reduction of production costs and thus, a higher demand over the years. This loop is accelerating over time, which results in the demand gap further increasing over time. This loop and hence this gap, is influenced by the share of 2G ethanol reached in 2030. Consequently the question arises, how does a higher initial share of 2G ethanol (e.g. 1.5% or 3.6%, following the Renewable Energy Directive (RED II)) influence the real demand of 2G ethanol?

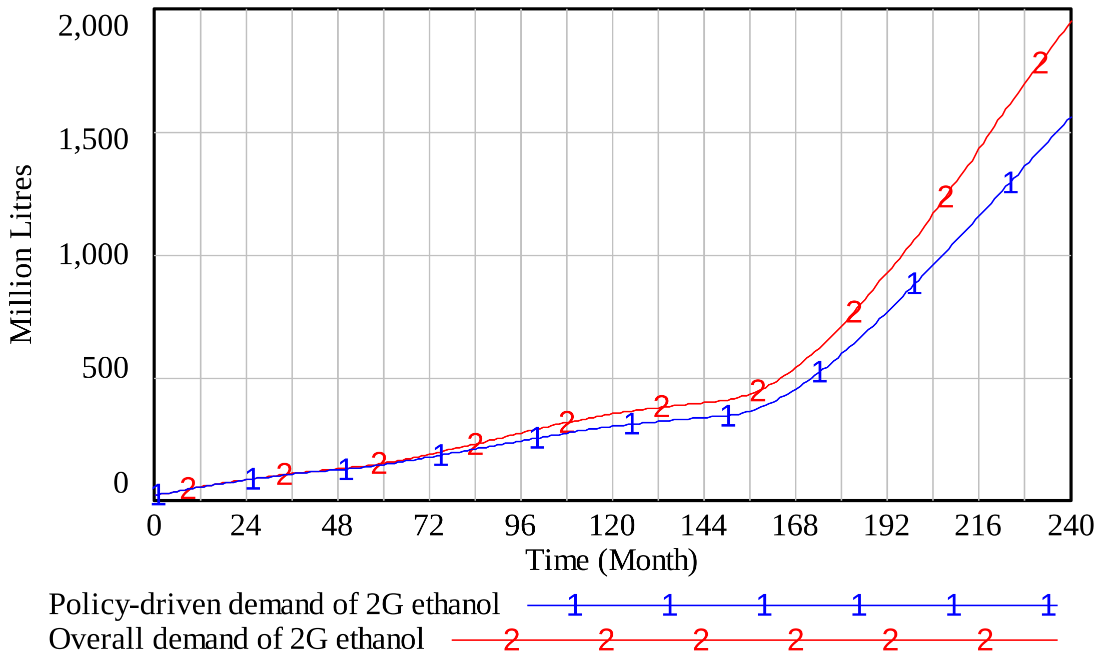

Figure 6: 2G ethanol demand by policy-driven share in total fuel consumption 1.5 % in 2030

As expected the figures show that the learning effects have a stronger impact on the overall demand, if the initial share of 2G in total fuel consumption is increasing. Figure 6 shows the run for an initial share of 1.5% and figure 7 for 3.6%. As the diagrams show, the higher the initial share of 2G ethanol, the faster the gap between the policy-driven demand and the overall demand is growing. This derives due to a lower price level, leading to additional demand beyond the policy-driven demand. While the gap holds a value of 100 million litres for an initial share of 0.5%, it is 350 million litres for 1.5%, and approximately 850 million litres for 3.6%. Finally, figure 8 illustrates the development of the gap between initial demand and real demand over time (comparison between Fig. 5, 6 and 7, see also Fig. A-1).

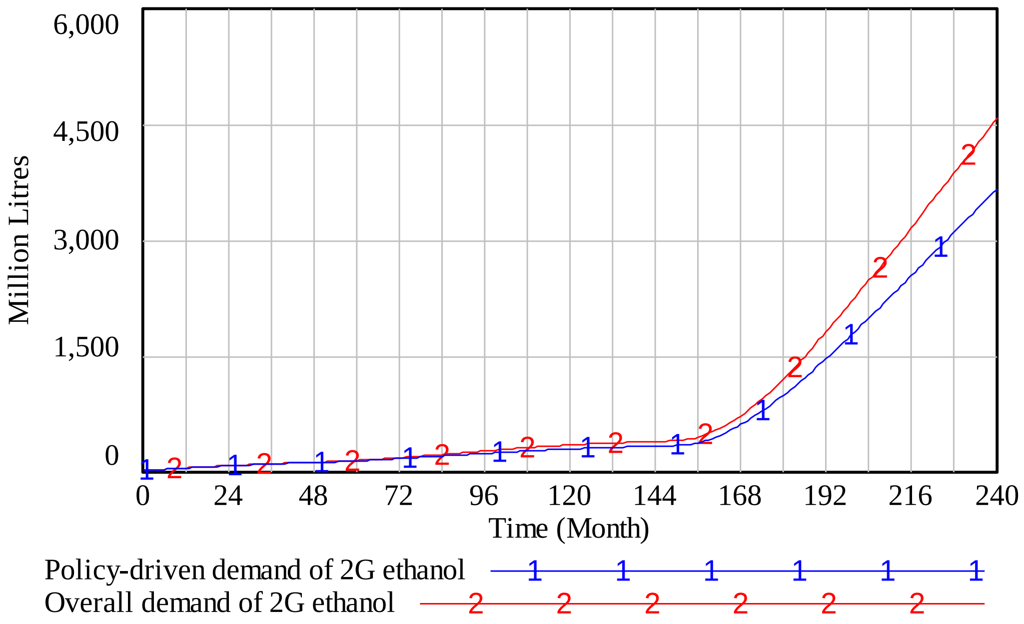

Figure 7: 2G ethanol demand by policy-driven share in total fuel consumption 3.6 % in 2030

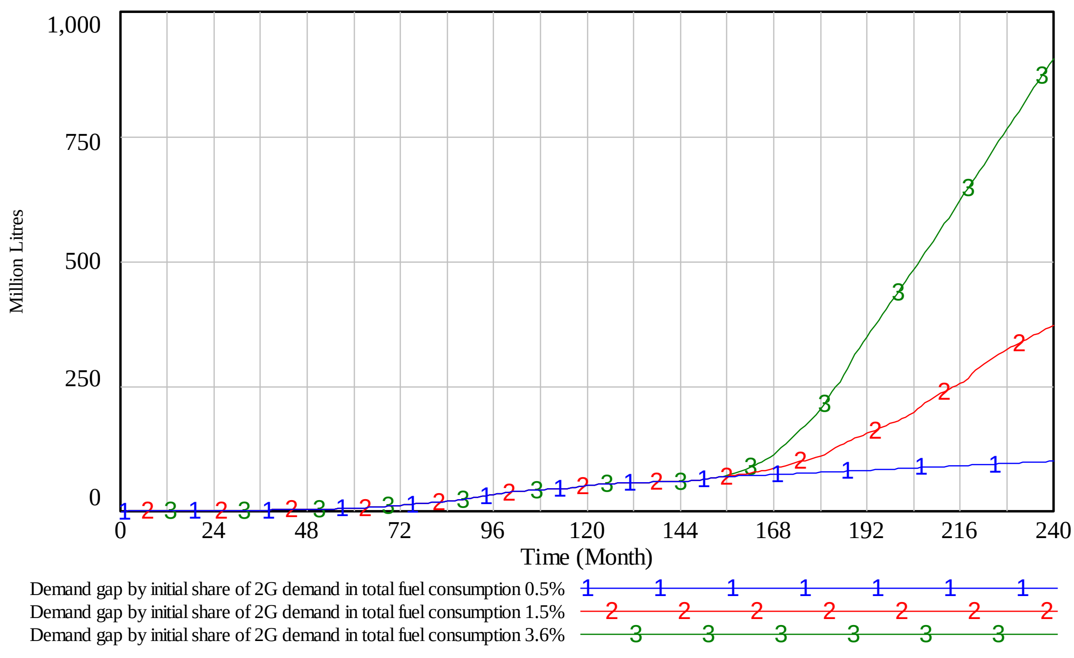

Figure 8: Gap between policy-driven and overall 2G ethanol demand for various shares (0.5%, 1.5%, 3.6%)

4. Conclusion

This paper takes the first step towards analyzing the interactive effects of policy incentives and learning effects on 2G ethanol demand. Therefore a System Dynamics model was first developed, which reproduces the system structure in a very simplified way, but is able to provide initial insights into the system's behaviour. By means of simulated tests it was possible to develop the first hypothesis about the dynamics of 2G ethanol demand. Through the simulations we can show that the learning effects influence positively the reduction of process costs and the 2G ethanol market price, thereby influencing the 2G demand positively. This effect is enhanced by reinforcing policy incentives in terms of indicative targets (Renewable Energy Directive (RED II)).

However, this dynamic analysis is just the first step based on simplified systemic structures and is still ongoing research. The production costs, for example, include a couple of other factors that have not been regarded so far. Moreover, feedback influences on feedstock may arise in the case of large scale production, as residues and straw might become scarce. Furthermore, land use changes and/or feedstock price increases may occur and affect production. Summing up, there are still a few loops, restrictions, resource limitations and political decisions that are not included in this first model so far. Nevertheless, these effects may take place in a more detailed System Dynamics model in the future.

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Appendix

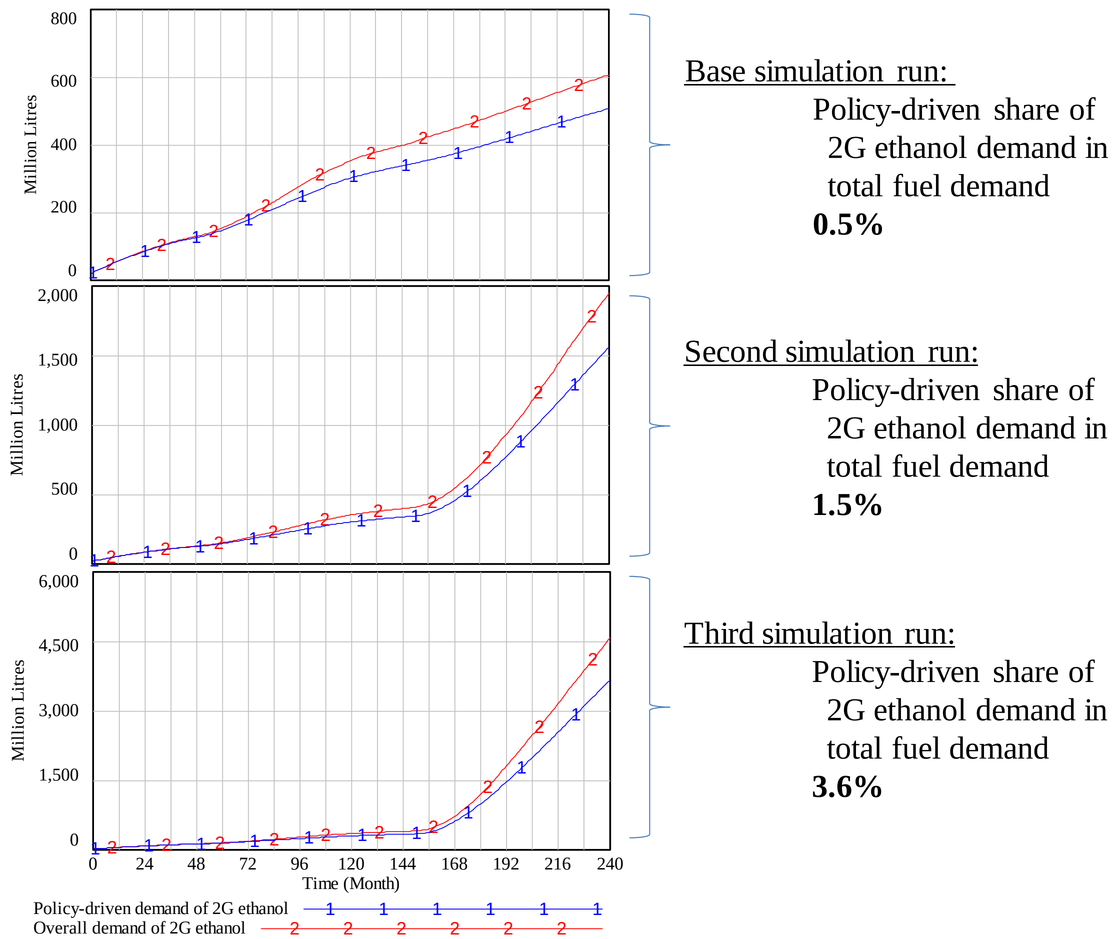

Figure A-1: 2G ethanol Demand by Initial Share of 2G Ethanol in Total Fuel Consumption for 0.5%, 1.5% and 3.6% in 2030