Perspective

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Variable demand as a means to more sustainable biofuels and biobased materials

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Abstract: Expanding the use of biofuels is controversial because of concerns about competition with food. Here we describe how varying the biofuel demand could help address these concerns. Variable biofuel demand can be implemented through market or policy mechanisms that adjust biofuel production according to feedstock availability, expanding or contracting in response to supply surplus or limitations. Based on a survey, an expert workshop, and relevant literature, the effects of a variable biofuel demand approach are evaluated with respect to food security, agricultural productivity, detrimental land-use change, and feedstock competition with biobased chemicals and materials. Here we provide evidence that variable biofuel demand can enhance the synergistic development of agriculture, renewable biomass feedstocks and biofuels, but implementation faces several challenges. Recommendations are provided for governance options to tackle these challenges. © 2020 The Authors. *Biofuels, Bioproducts, and Biorefining* published by Society of Chemical Industry and John Wiley & Sons, Ltd.

Key words: biofuels; food security; ILUC; agricultural productivity; biobased chemicals; bioeconomy policy; market competition

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Introduction

Bioenergy is often viewed as an essential and large component in strategies to reduce greenhouse gas (GHG) emissions to limit climate change.[1–3] The potential competition for feedstock between food, feed, biofuels, and other non-food applications (materials and chemicals), however, has emerged as a barrier for large-scale use of bioenergy.[4] This has led to extensive research on approaches for more sustainable bioenergy production and explicit calls for policies that will limit potential negative impacts of biofuel production.[2,5–7]

Varying the demand for – and production of – biofuels may provide a valuable solution to concerns about competition with food. Production of bioethanol from sugars and starches or biodiesel from fats and oils can be increased in times of excess feedstock availability (and low feedstock prices), and reduced when feedstock availability is low (and feedstock prices are high). Accordingly, feedstock for biofuels can provide a 'virtual food reserve', meaning that feedstock can be shifted when required to meet priority food demand. This concept is not new. Food and Agriculture Organization Director General José Graziano da Silva, for example, advocated 'Flexible Biofuel Policies for Better Food Security'.[8]

Biofuels represent a major source of renewable energy. They play an important role in the realization of the UN sustainable development goals (SDGs) especially in the context of energy security (SDG-7) and climate change (SDG-13). Biofuel production is also linked to health (SDG-3), employment, and growth (SDG-8), rural development (SDG-2), soil management (SDG-15), and water quality (SDG-6).[9] Bioenergy, like all sources of energy, can have negative impacts if resources are developed and deployed improperly. Three key concerns about biofuels and corresponding SDGs are: food security (SDG-2); detrimental indirect effects on forests and biodiversity, often described as 'indirect land use change' or ILUC, and associated GHG emissions and biodiversity loss (SDG-15), and availability of sustainable biomass for other uses (chemicals and materials).[10]

Despite major increases in global food availability, the number of undernourished people, facing chronic food deprivation, increased to nearly 821 million in 2019, up from 785 million in 2015.[11] Reducing global hunger crucially depends on improving living conditions in the rural areas where most poor and malnourished people live.[12] This requires more investments in agriculture and rural development.

Biofuels can positively affect crop production, input use efficiency, farm income, and agricultural investments – thereby increasing crop yields.[12–16] Biofuel production can improve health conditions and employment, and provide opportunities for women and poor households.[13] These positive effects can provide an important positive impulse for food security and livelihoods in both rural and urban areas. Having multiple markets for their products brings more resilience to farmers.

A number of studies demonstrated potential advantages of enhanced biofuel production,[17–20] but improper development of biofuel production also brings risks, especially in areas where land tenure and resource access rights are not well established, and health and environmental standards are insufficiently respected. A balanced approach is therefore needed.

This paper evaluates possible impacts of a *variable biofuel demand approach*, i.e. a policy or market mechanism that adjusts biofuel production to changes in biomass availability as determined by variations in feedstock supplies, typically driven by crop yield and stocks. The idea is presented in Fig. 1.

Meeting future food, feed, fuel, and material demand on available arable land will require considerable improvement of crop yields. Research on yield gaps suggests that there is a huge opportunity to increase yields on current cropland, especially in Africa, and parts of Asia, Eastern Europe, and the Americas.[21–23]

This paper presents the outcomes of a project that evaluated potential impacts of variable biofuel production as an instrument to address some of the primary concerns associated with the production of biofuels from starches, sugars, and oilseeds, e.g., using feedstocks such as maize, sugarcane, and soybeans. Biofuels that utilize these resources as the primary feedstock are described as conventional or 'first-generation' biofuels. The project consisted of a literature review, a survey, and a dedicated workshop.

Over 50 international respondents offered their views on a variable biomass demand policy through the survey.[24] These views were discussed in a dedicated workshop with experts from the USA, Canada, Belgium, Germany, and the Netherlands.[25] Highlights from the discussions and recommendations for improving policies to support more

A Variable Biofuel Demand Approach

Varying production volumes of biofuels according to feedstock availability. The policy aims to:

- Increase food security of conventional agricultural crops, where feedstock for biofuels is a virtual reserve
- Provide incentives to increase agricultural output per hectare of land
- Reduce risks of detrimental indirect effects
- Ensure availability of feedstocks for biobased economy

Figure 1. Variable biofuel demand approach.

sustainable biofuel production are presented here. A variable biofuel demand policy will be evaluated below in terms of potential impact on food security, agricultural productivity, detrimental indirect effects on land, forests, and biodiversity and feedstock supply for the biobased chemicals and materials.

Variable biofuel demand

Survey

The purpose of the survey was to document opinions on how the concept of variable biofuel demand could affect sustainability issues for biofuels and other biobased applications (materials and chemicals) based on conventional agricultural crops. The survey included ten statements on which respondents could indicate the extent to which they agreed or disagreed with the statements by selecting one of the following five answers: 'strongly disagree', 'disagree', 'neither agree nor disagree', 'agree', or 'strongly agree'. Respondents had the option to provide comments to explain their answer. A list was compiled of 305 people who would be knowledgeable about the topic, covering a wide range of disciplinary backgrounds and geographical locations. They were invited by e-mail to participate in the survey and 52 people (17%) responded with a complete survey. The majority had a background in environmental sciences (37%). The other disciplines included agriculture (21%), economics (10%), and chemistry (8%). About a quarter had 'other' backgrounds including the renewable energy and biofuel sector. The majority of respondents were working in research/consultancy (58%), while some were working in government (12%) and industry (10%), and only 1 was working for a non-governmental organization. The option 'other' represented 19% and included universities, industry associations and international organizations. Regarding the region of respondents, where there was possibility to choose multiple regions, most of them were working in Europe (50%) and North America (23%). Some were also working in South America (12%) and Australia/Pacific (12%); few were working in Africa (8%), while only 1 respondent was working in Asia.

A 'weighted score' was calculated as the average for the scores plus or minus the standard deviation (STD). Table 1 presents the ten statements and the responses of the respondents ranked according to the agreement score. Six statements had a positive score, indicating most respondents agreed with these statements. The strongest agreement

Table 1. Overview of responses on 10 statements about a variable biofuel demand policy allowing respondents to select one answer: strongly disagree (–2), disagree (–1), neither agree nor disagree (0), agree (1) or strongly agree (2). The weighted score is the average for the scores plus or minus the standard deviation (STD).[24]

Statements	Weighted score	STD	–2	–1	0	1	2
Very low food prices are equally bad for food security as **very high food prices.**	**0.85**	1.07	6%	6%	13%	48%	27%
A variable biofuel demand will have a **positive effect on agricultural productivity** leading to additional financial investments in production capacity and technology.	**0.44**	1.32	10%	19%	13%	33%	25%
A variable biofuel demand will have a **positive effect on food security**, because biofuels serve essentially as a virtual food reserve.	**0.35**	1.23	8%	21%	19%	33%	19%
A variable biofuel demand will **lead to higher agricultural output per hectare**.	**0.31**	1.37	12%	21%	17%	25%	25%
A variable biofuel demand will **reduce the risk of** indirect land use change (**ILUC**)	**0.15**	1.21	8%	29%	17%	33%	13%
A variable biofuel demand will **make investments** in the first-generation biofuel industry **too risky**.	**0.06**	1.13	8%	27%	27%	29%	10%
A variable biofuel policy will be **effective only within protected markets** and not on a global scale.	**–0.29**	1.05	12%	35%	29%	21%	4%
Biomass feedstocks for **chemical industries must be given priority** over feedstocks for biofuels.	**–0.31**	1.20	15%	35%	25%	15%	10%
Sustainability certification will prevent ILUC.	**–0.37**	1.07	15%	31%	33%	17%	4%
Most biofuels policies worldwide **already have mechanisms** to vary production volume; there is no need for a variable biofuel demand.	**–0.56**	0.78	8%	50%	32%	10%	0%

concerned the importance of price stability. Questions in the middle of this ranking suggest a lack of agreement or a lack of a strong opinion among the respondents such as those related to indirect effects and risks of investment. Four statements had a negative score. For these statements many respondents (25–33%) chose the 'neither agree nor disagree' option. The least agreement was seen for the statement 'Most biofuels policies worldwide already have mechanisms to vary production volume.' According to the survey results, most existing biofuel policies work with fixed quotas and lack flexibility to vary production volume.

The opinions of the respondents give a good indication of the broad range of views and understanding that exist on the various issues that are important when discussing a variable biofuel demand approach. The results from the survey were used as a starting point for the expert workshop. The authors acknowledge the inherent limitations associated with the survey, including the potential for respondents to hold different perceptions and interpretations of terms and concepts such as 'virtual food reserve'. The survey results are therefore considered within the context of additional comments submitted by respondents. Information from the literature, comments made in the survey, and discussions during the workshop are presented below.

Food security

The global population is projected to grow to 9.7 billion by 2050, possibly exceeding 11 billion by the end of the century. To meet projected food demand, farmers need to produce almost 50% more food and feed in 2050 than in 2012.[26] The Food and Agriculture Organization (FAO) projects that output should more than double in sub-Saharan Africa and South Asia, and increase by about one-third in the rest of the world.[26]

Food production is currently not very efficient:

- Nearly two thirds of global agricultural lands are underutilized with low animal densities[27] and minimal contributions to dietary protein,[28] offering opportunities for increased output of crops, animal protein, or other services.[29]
- Crop yields in many regions are far below potential, partly due to poor management and inappropriate technology use.[30]
- Valuable resources are lost due to poor treatment of soils, inefficient water use, etc.[31]
- On average, one third of harvested food is wasted each year.[26]
- Average post-harvest losses omit the fact that potentially more food is simply abandoned in the fields each year pre-harvest due to excessive supplies and low prices at harvest time.[32,33]

Increasing supply depends largely on reducing wastes, yield improvement, and enhancing input-use efficiency, as options for area expansion in most regions are limited due to lack of suitable land for farming, whereas in other regions land conversion may not be desirable due to the associated environmental impact.

Economic theory suggests that increasing demand or restricted supply will lead to higher food prices and this theory is supported when prices rise in response to unexpected shocks due to extreme weather, political interventions, or other market disturbances. However, global food prices have persistently declined over past decades despite increasing demand, largely thanks to increasing efficiencies in production systems and global trade.[7] Large and sudden price fluctuations can be detrimental to producers and consumers alike, particularly in isolated food markets that have limited capacity to absorb them.[34] Such fluctuations and the resulting variations in income, represent risks to farmers and lenders. The volatility of international markets for agricultural commodities in recent years intensified concerns about price risks among farmers in many countries. Producers are generally more concerned about the prospect of low prices because a lower income may threaten the viability of their business in the long term.[35] Meanwhile, the ability of poor households to ensure sufficient nutrition and fulfill other basic needs can be compromised when food prices are too high. Farmers are also less willing to invest in productivity-raising assets when prices are unpredictable, and this may encourage them to take sub-optimal investment decisions.[36]

The links between biofuels and food security are complex.[7,12] Biofuels provide both risks and opportunities. Higher food prices can threaten the food security of the poor, many of whom spend more than half of their income on food. To date, however, no lasting price increases appear to have been observed following the implementation of biofuel policies.[37]

Biofuels, directly and indirectly, offer opportunities for rural populations. They can harness agricultural growth, support rural development and, consequently, reduce poverty.[38] This mostly refers to local and regional processes stabilization of biomass off take (e.g. for dual – food plus energy – purposes), diversification of production and development of local biorefineries. Practical experience from pilots in the Netherlands Programme for Sustainable Biomass has shown that this can be achieved when local policies are designed carefully, taking care of local sustainability restrictions and proper capacity building.[39]

To be truly sustainable, biofuel production must strike a balance between its benefits and its potential hidden costs, between energy security and food security. Policies can

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be more effective if they are flexible enough to counteract varying market conditions and respond to changing human needs.

How can a variable biofuel demand contribute to food security?

The implementation of variable biofuel demand aims to offer farmers a secure market for agricultural production. In times of abundance, the surplus of agricultural production can be absorbed by the biofuel industry, thereby limiting a drop in prices. By giving food demand priority over biofuels, competition with food is avoided when supply of feedstocks is low.

A variable biofuel demand for non-food applications can help to foster favorable conditions for investment. Investments in agricultural production are often hampered because of fluctuating demand and prices. Securing an outlet for agricultural products stimulates investments in production technology and capacity, as observed in some recent case studies and analyses.[15] Increasing agricultural productivity (and therefore closing the yield gap) in turn is stimulated by investing in production capacity. There are several examples that provide evidence of positive effects of biofuel production on rural investment, agricultural productivity, and food security in Brazil (sugar cane) and the USA (corn),[12] Mozambique (cassava),[13] and Hungary (maize).[15] The US and Brazil cases specifically illustrate flexibility to shift from biofuel to food production in response to changes in feedstock availability and price.[24,25] It was stressed, for example, that the impact of the USA 2012 drought on food security (prices and availability) was limited, in part due to adjustments in ethanol production, which freed maize for other markets, and in part by investments in storage capacity made by farmers following a number of years with profitable cropping for biofuel markets.[25]

Just over half of the total respondents (52%) who participated in the survey, and 73% of the respondents with an agricultural background, agreed with the following statement: 'A variable biofuel demand will have a positive effect on food security because biofuels serve essentially as a virtual food reserve, thereby avoiding feedstock scarcity and high food prices. This provides more stable feedstock availability and price for food, feed and chemical industries.' In addition, several respondents provided comments to emphasize that the production of food, and biofuel can be complementary and that having multiple markets for agricultural products will improve the supply security and reduce price volatility (Fig. 2). Experts with an agricultural background who are professionally familiar with, knowledgeable about, and active in agriculture, generally support bioenergy / bioproduct uses. Respondents with less first-hand or professional knowledge are less supportive.

Reasons provided by respondents who did not agree include: the current free market system is functioning well; the biofuel feedstock share is relatively small and the feedstock price is influenced by many other factors (e.g. fossil price); food reserves may trigger speculation.[24] Some respondents commented that food insecurity is not the result of limited food availability but primarily an issue of (lack of) wealth, social stability, and access to markets.

A number of key principles were voiced during the expert workshop for a sustainable bio-economy with 'food first: ensure the primacy of food security' as one of them.[40]

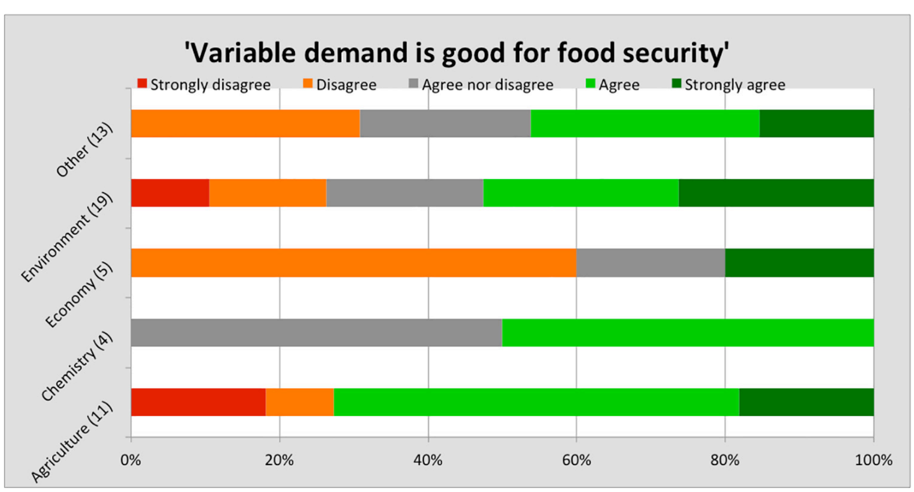

Figure 2. Agreement with statement 'A variable biofuel demand will have a positive effect on food security', by disciplinary background.[24]

Agricultural productivity

Agronomists distinguish different crop yield levels. The 'potential yield' is the maximum yield level that can be realized with optimum planting densities and times, under prevailing radiation, temperature and air-CO_2 conditions, in the absence of shortages of nutrients or water, with no major weeds, pests, or diseases. Water limited potential yields are potential yields in rainfed conditions as determined by precipitation amount and distribution during the growing season and soil properties influencing the crop water balance, such as soil depth and texture. Actual farmer yield levels are always below the yield potential because, even with the best possible socio-economic context, it would not be cost-effective for farmers to apply the level of inputs that is needed to reach yield potential. Similarly, it would be very difficult to reach the level of perfection in crop management that is needed to avoid completely yield reductions due to insufficient nutrient supply and incidence of pests and weeds over the entire crop season. The difference between potential yield (or water-limited yield in the case of rainfed crops) and average farmer yield is called the 'yield gap'.

Farmers in favorable agricultural regions often realize up to 70–80% of the potential yield level,[41] as, for example, in the case of corn in the USA and wheat in Western Europe. However, in many other regions the actual yield is much lower. Main factors depressing yields are biotic (caused by infestations of weeds, pests, and diseases), abiotic (shortages of water or nutrients), or related to institutional (poor access to machinery, inputs, or information) and economic factors (poor management or planning, lack of road and market infrastructure). An overview of yield gap analysis in wheat production in Europe is presented in Fig. 3.

Decisions on allocation of inputs (machinery, fertilizers, agro-chemicals), but also time and information dedicated to crop production are made before the start of the growing season, i.e. when weather and market conditions are unknown. Stable demand and robust conditions for investments in machinery and other capital goods (roads, storage facilities), knowledge or skills will improve farmers'

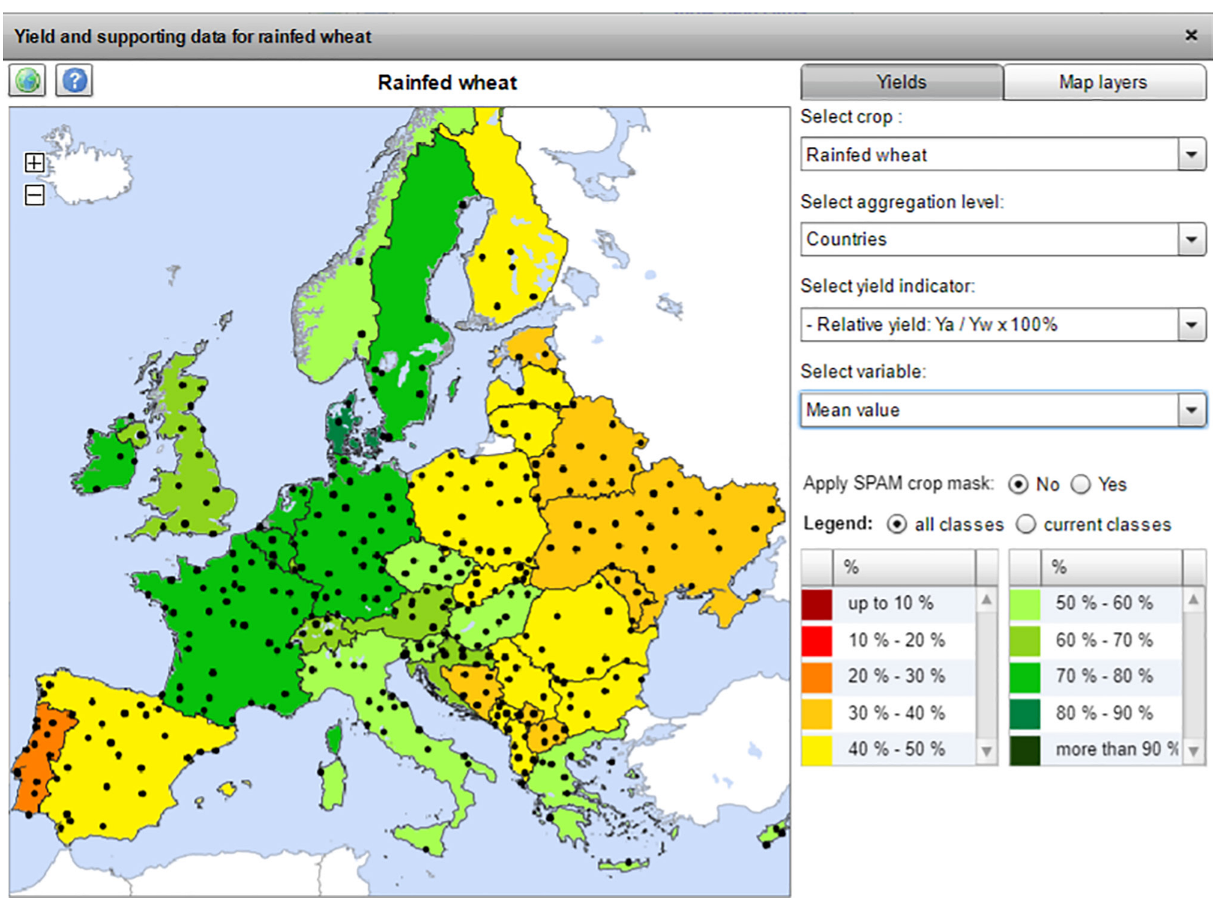

Figure 3. Yield gap for wheat in Europe expressed as percentage of water limited potential yield (Yw), at country level. Source: Global Yield Gap Atlas.[21]

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willingness and abilities to invest to improve growing conditions.

How can a variable biofuel demand contribute to agricultural productivity?

According to a majority (58%) of the survey respondents, variable biofuel demand will have a positive effect on agricultural productivity. A considerable minority (29%), however did not agree.[24] Some respondents noted that a positive effect may be found when variable biomass demand will stabilize crop markets without unduly increasing risks for investors. An additional outlet for excess amounts of crops is expected to increase income security for farmers, enabling them to increase investments and improve productivity. However, other respondents believe variable biomass demand can cause a decline in investments and this would have a negative effect on productivity. It was emphasized that the impact of a variable biomass demand is context specific; not all farmers will be able to benefit and how policies are designed and implemented is very important. Some fear that only large farmers in regions with a favorable climate and infrastructure will profit.[24]

There is a clear relation between the professional background of the respondents and the way the question on agricultural productivity was answered (see Fig. 4). Most agricultural respondents agreed (73%) and respondents from environmental sciences were also in favor (63%). Economists and chemists are less optimistic.[24]

During the workshop, it was acknowledged that the growing global population and changing diets will increase food demand by 50–70% in the next 35 years.[42] This means that, to meet food demand on existing cropland area, global crop yields will have to increase with 1.2–1.3% annually until 2050.[25] Yield gaps are especially significant in Eastern Europe and Africa, and policies that stimulate private investments in agricultural production capacity (related to cultivation activities, logistics, marketing or research) are needed.

In the USA, increased returns from biofuel crop production (maize) in recent years have provided an incentive for farmers to invest (rather than pay profit tax) in new machinery, silos, precision-agriculture technologies (which enhance input-use efficiency and yields), and buildings, consequently boosting farm productivity.[15,19] Increased on-farm storage capacity helped to stabilize crop supply in a drought year, directing its use to food or fuel according to the price incentives.

Overall, it was concluded that a variable biofuel demand approach could draw essential additional investment and research and development for crop intensification, provided that good crop management is in place.[25]

Detrimental indirect effects on land and resources (or indirect land-use change, ILUC)

Indirect land-use change is simulated by models to occur if the cultivation of crops for biofuels and other biobased applications displaces traditional production of crops for food and feed purposes. Assumptions enabling ILUC include inelastic food demand and limited global food supplies. Such assumptions are not applicable when bioenergy markets absorb surplus production. However, when common ILUC modeling assumptions are applied, agricultural expansion necessarily occurs and displaces other land classes within the

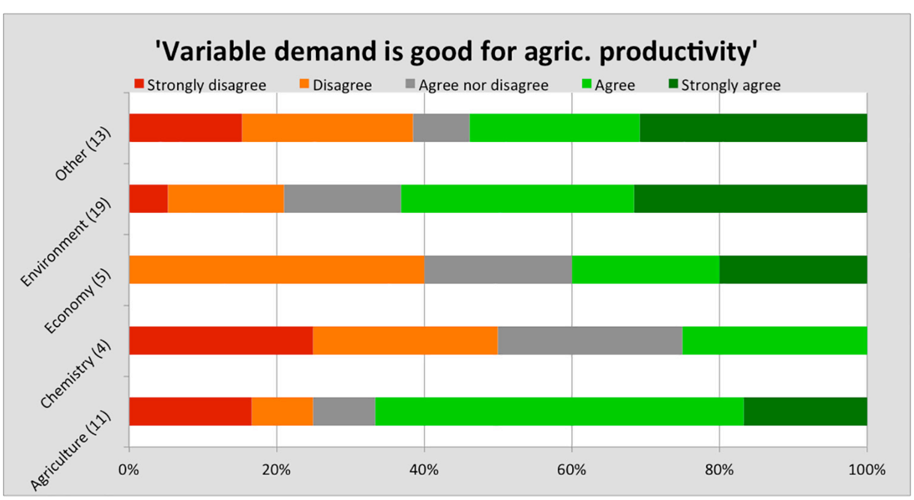

Figure 4. Agreement with statement 'A variable biofuel demand will have a positive effect on agricultural productivity', by disciplinary background.[24]

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model framework. When the expansion extends into forests or other lands that were previously not actively managed, significant impacts arise. Most observers consider effects to be highly detrimental whenever land clearing occurs in forests, wetlands, peat lands, or other areas with high conservation value for biodiversity, high carbon stocks, or where clearing leads to high greenhouse gas (GHG) emissions.[43,44]

The consequences of clearing new land for agriculture, and the associated GHG emissions and biodiversity losses, are among the main concerns related to increased biofuel production. Many papers (e.g., Searchinger *et al.*)[45] assume that the competition caused by bioenergy must result in such detrimental environmental impacts. However, other studies suggest that the actual influence of biofuel policies may be to reduce rates of deforestation and detrimental impacts by stimulating practices for more efficient and sustainable production. Studies also note that the sugarcane industry in Brazil, following 500 years of poor social and environmental performance, underwent fundamental transformations to improve social and environmental responsibility in response to biofuel market demands.[2,29,46,47] Besides GHG emissions, other environmental and socio-economic impacts of expanding biofuel production are taken into account in certification schemes that aim to ensure sustainability. Similar pressures appear to be influencing some traditional maize and soy farmers who target biofuel markets, with increasing adoption of conservation tillage and precision agricultural practices.[48] A series of studies that look at empirical evidence rather than only model simulations, found little support for negative indirect effects and substantial potential for beneficial indirect effects.[7,15,49–51] By emphasizing sustainability, the net effect of biofuel policies appears to be significantly beneficial in terms of improving land management compared to the status quo, which is another essential component to achieve SDGs and future climate goals.[52] Dimitriou *et al.*,[17] Heaton *et al.*,[18] Dale *et al.*,[19] Brandes *et al.*,[20] and Zvinavashe *et al.*[13] demonstrate that integration of food production and bioenergy may offer a range of advantages compared to conventional systems focusing on a single food market. Attention to the sustainability requirements associated with bioenergy markets should result in improved water quality, biodiversity, and soil quality enhancement.

The concept of ILUC was conceived in economic simulation models. In the real world, all real changes in land cover and land management can be monitored and their causes analyzed. In such a real world, there is no ILUC but rather a range of causal factors for each observed condition. Thus, it is important to monitor activities, analyze causes for detrimental effects, and take corrective actions as appropriate. Standards promoting sustainable biofuels contribute to increased monitoring and analysis of the corresponding supply chains.[53] Recent work by FAO[54,55] illustrates how negative impacts caused by past land use change can be mitigated; they provide examples of good practices that can combine the sustainable production of food, bio-based products, and bioenergy, including biofuels. Several studies also highlight approaches for biofuel expansion to take place while minimizing the risks of ILUC, such as double-cropping, agro-ecological zoning and integrating the production of food and bioenergy through sustainable agricultural intensification.[26] A study assessing direct and indirect LUC dynamics in Brazil towards 2030 with an increase in the global demand for bioethanol, shows that the implementation of LUC mitigation measures (increased agricultural productivity, shift to second-generation ethanol, and strict conservation policies) could have a substantial contribution to the reduction of loss of natural vegetation (forest, grass and shrubland) and LUC-related emissions of bioethanol.[56] It is further pointed out that there are already ongoing efforts in implementation of these measures in Brazil. Diogo *et al.* developed a framework to assess technical potential for economically viable biofuel production avoiding ILUC.[57]

How can a variable biofuel demand reduce the risk of ILUC?

Respondents to the survey have mixed views on the statement 'A variable biofuel demand policy reduces the risk of indirect land use change (ILUC) by stabilizing prices and stimulating higher productivity per hectare on existing cropland.' Almost half (46%) of the respondents agreed with the statement, especially those with a background in agronomy. But 37% of respondents did not agree with the statement. Many respondents commented that biofuel production is one among many drivers causing changes in land cover and management. Other factors include timber, minerals (oil, gas and other extractive industries), corruption, and land speculation. In addition, several of the people surveyed, as well as the expert workshop participants, observed that the assumed impacts of ILUC cannot be determined based on model simulations; the real-world impacts need to be measured. And the net effects of biofuel markets and policies need to be assessed relative to prior trends. An emphasis on carbon accounting is appropriate and necessary, and is being supported in unprecedented measures thanks to biofuel markets. Several workshop participants agreed that ILUC controversies will persist due to the vague definitions and generalized classifications used by modelers. Actual effects on forests and biodiversity need to be studied in the field,

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applying a scientific approach that tests hypotheses based on observations, measurements and analysis rather than projections based on assumptions. Given current reliance on models, the ILUC debate will not be resolved any time soon.[58,59]

Linkages between economic development, governance, and deforestation have been observed for decades; economies with high scores for per capita income, human development, and governance (including anti-corruption) make the transition to stabilize deforestation.[60–67] Limited or ineffective governance capacity (and corresponding increases in corruption) are also correlated with higher rates of deforestation.[68,69] It is widely accepted that undesirable tropical deforestation is a systemic and context-specific phenomena and to be effectively addressed, requires institutional reforms at multiple levels.[69,70] When other economic opportunities are limited, governments with public lands available often turn to 'development' of frontiers via projects, colonization programs, roads, and new timber or resource extraction concessions. For example, in the 1970s–1980s, Brazil's policies were designed to move 'as many people as possible . . . [to] the "empty" forested areas of the Amazon… [and] these policies can be viewed as principal causes of extensive deforestation.'[69] New pioneers stake claims or try to profit from the 'improvement' associated with clearing forests; agriculture is not economically feasible given poor infrastructure and lack of markets.[7,71] A variable biofuel demand can provide incomes and development in the previously settled areas, where access to markets already exists. The FAO estimates that at least one third of all food produced globally goes to waste each year, much of it being left in fields to rot.[33] The agro-ecological zoning and identification of areas that are off limits due to high conservation values, are recent constructive steps impacting agricultural systems with large biofuel coproducts, such as Brazil.[47,72] In sum, variable demand policies, working with established industries, can and must expand upon 'best practices' to provide options that increase productivity while reducing detrimental impacts such as deforestation.[19,54]

Securing feedstock supply for the materials industry

As both bio-based materials and biofuels rely on the same raw material, appropriate policies are required to create fair conditions for both sectors – a situation which is often called a 'level playing field'. The EU's Renewable Energy Directive (RED) resulted in increasing biomass demand from the energy and fuels sector. This puts pressure on biomass availability for the non-incentivized bio-based materials industry.[73,74]

Bio-based materials offer potentially larger environmental benefits than biofuels / bioenergy (e.g. more GHG emissions savings, circular economy), as well as social (e.g. employment, also in the rural environment) and economic impacts (e.g. value-added, resource efficiency).[76–80] It is likely that even greater benefits can be attained in the near future as processes are still being further optimized.[81] Using biomass for consumer goods can potentially keep carbon captured longer. By applying principles of cascading, biomass can also be used for materials multiple times by recycling, which is a main characteristic of the circular economy.[82] At the end of their life cycle, biomaterials can be used to generate power or heat.[77] Bio-based materials also may bring new functionalities compared with their fossil-based counterparts (e.g. biodegradability and reduced toxicity).[83–85] A comparative overview of using biomass in materials versus use for energy purposes is provided in Table 2.

Biomass is the only alternative to fossil resources for chemical production apart from capturing and production from CO_2 using electrochemistry, which is still in an early development stage.[86,87] Biofuels are widely expected to be the primary fossil-fuel alternatives for industries such as aviation, marine transport, and heavy freight.[88] Furthermore, the feedstock supply chains developed for energy use can act as drivers for biobased materials deployment.

Sugars, starch, and oils needed currently for the production of bio-based products can also help kick start other bio-based industries.[89] Technologies based on lignocellulose feedstocks are in various stages of development. In terms of fuel yields per hectare, sugar cane and sugar beet are more efficient than lignocellulosic crops.[90] If efficient cellulosic biofuel technologies, with higher efficiency, become viable over time, the first-generation feedstock may serve as a bridge for their implementation.[76]

Bio-based chemical plants have higher capital cost due to longer value chains and accordingly have a higher share of fixed operating costs, making the financial viability of the business sensitive to capacity changes. On the other hand, the feedstocks account for a much larger share of the total costs for biofuel plants that utilize conventional commodities such as maize and soybeans, from 58% to 80% of operating costs,[91–93] making the financial viability of the operations relatively less susceptible to changes in production capacity. And while some bioenergy supply chains can temporarily fall back to the use of fossil fuels if biomass is unavailable, this is difficult for bio-based chemicals and materials plants specifically designed for processing biomass feedstocks. Furthermore, dedicated chemicals can be produced from biomass where an identical fossil-based product does not exist in replacement.

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Table 2. Comparison of energy and material use of biomass across different criteria (adapted from Nova[75]).

Criteria	Energy use of biomass	Material use of biomass
Greenhouse gas reduction	Significant reduction compared to fossil-based energy	Greenhouse gas mitigation at least equal but most often higher than energy use of biomass; long term carbon storage
Circular economy	No additional use or possibility to recycle	Possibility of multiple material use by recycling. At the end of life use for energy.
Employment, Value-added	Short value chains	Due to longer and more complex value chains can support up to ten times as much employment and provide ninefold value-added compared with energy use of biomass
Resource efficiency	For biofuel need to convert to hydrocarbons, lower mass yield	Most often higher land and resource efficiency compared with energy use of biomass
Added functionality	—	Bio-based products can offer added functionality compared with their fossil-based counterparts (biodegradability, reduced toxicity)
Renewable alternatives	Many options (solar and wind energy, hydropower and geothermal energy)	Only alternative to renewable carbon from biomass is direct use of CO_2, which is at a very early stage of development

A complete transition of the global chemicals market to biomass resources appears technically feasible over the long term. It was estimated that potential increase in yield in Europe would provide sufficient biomass for the production of all chemicals, 20% of transportation fuels, and 10% of EU electricity from biomass in 2030.[94,95] The total additional amount of biomass needed to fulfil the demand for biobased chemicals was simulated to be only 1–1.5% of the amount needed to fulfil the demand for bioenergy.[96] Accordingly, the full exclusion of demand for biobased chemicals was found to have a negligible impact on the marginal costs of key feedstocks.

How can a variable biofuel demand contribute to securing feedstock supply for the materials industry?

We propose that if biofuel production is adjusted in response to biomass availability and prices, this variable demand can offer a feedstock supply cushion to help meet needs for food, materials, and chemicals. Half of the respondents (50%) disagreed with prioritizing feedstock for the chemical industry; the other half agreed (25%) or answered neutrally (25%). Respondents who agreed provided the following arguments: (i) Considering the value pyramid first chemicals then fuels should be produced. (ii) Chemical production has more specific requirements than fuel production and should have priority use of feedstocks. (iii) Biobased chemical production leads to higher GHG savings, employment, and value, and therefore policies should create incentives for their production.[24]

Several respondents who disagreed with prioritizing feedstock for chemical industries, along with experts in the workshop, commented that markets should be allowed to operate freely and efficiently to allocate resources among different sectors and bio-based applications.[24,25] This, however, requires a level playing field while current incentives given to biofuel production are causing market distortions. This could be solved by establishing a new political framework providing a balanced support that allows the highest resource use efficiency, the highest value-added, the highest employment, and the greatest climate protection/climate change mitigation to be achieved. In this way, policies can support the market so that biomass can be allocated in the best way from a sustainability perspective. For that, an expert pointed out that the entire bio-economy needs to be considered and same set of sustainability criteria need to be brought for all biomass applications including food and feed industries.[25] Furthermore, the development of bio-based products should continue to be supported so that they can become cost competitive with their fossil-based counterparts. Research on biorefineries delivering food/feed ingredients, materials/chemicals and fuels/energy should be given momentum as synergistic effects occur which provide more value than separated production.[97–100]

Policy experiences and recommendations

Existing policies with mechanisms to vary biofuel production volume

Current biofuels policies already include elements of variable biofuel demand. In Brazil, Pro-Alcohol – the main biofuel stimulation program initiated in the 1970s, had three major

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components: (1) guaranteed purchases by the (state-owned) oil company, (2) low-interest loans for ethanol producers, and (3) fixed gasoline and ethanol prices for consumers. Mandatory blending rates were adapted several times to accommodate fluctuations of cane and fossil oil prices.[101] Brazil has adjusted the ethanol mandate eight times since 2006, fluctuating between 20% and the current 27% blend in common gasoline (or E27 gasoline), in response to diverse factors including global sugar and oil prices and exchange rates.[102] Ethanol demand in Brazil increased by more than 30% since 2007.[103] The introduction of flex-fuel (FFV) technology has been a critical factor in facilitating increasing ethanol demand in Brazil as well as variable demand mechanisms. Flex-fuel technology is currently found in 90% of cars and allows operation at any ethanol blend. Thus, depending on market prices, consumers can purchase pure ethanol or common gasoline. And the common gasoline pool can help absorb surplus, or shrink to free feedstock for sugar, by adjusting the mandated blend rate. The sugarcane industry has also gone through significant restructuring to allow parallel production of sugar and ethanol, more efficiently, in response to both domestic and foreign demand. As an example of this variable demand, Brazil sugar output was increased in response to high world market sugar prices in 2011–2012, and the mandated blend rate was reduced from 25% to 20%. Since then, declining sugar prices have led to higher blend mandates and increasing domestic ethanol demand.

Biofuels policies in the USA also have elements of variable demand. Under the Renewable Fuel Standard (RFS), the US Environmental Protection Agency is mandated to calculate annual renewable volume obligations (RVOs) for refiners, blenders, and importers of gasoline and diesel fuels based on demand and projections of qualifying renewable biofuels production. Notices of proposed rulemaking and a final rule are to be published in November of the previous year, although the notices are sometimes delayed.[104] Detailed compliance standards and waiver provision options were established for fuel suppliers, as well as a tracking system based on Renewable Identification Numbers (RINs – batches of biofuels that are registered). These numbers can be tracked, used, banked, or traded. By the end of the year, each supplier must have enough RINs to show that it has met its share of four mandated standards. In practice, year-to-year adjustment can be made of biofuel targets, depending on actual food and fossil market conditions.[104]

The most important factor facilitating variable demand is that RINS may be borrowed or banked.[105] Indeed, each year from 2005 to 2010, more ethanol was produced than was mandated under the RFS, leading to a substantial volume of banked RINs, some of which were subsequently used (withdrawn from the bank) when a drought severely limited US maize production in 2012.[105] The provisions allowing flexibility to bank and borrow RINs were incorporated explicitly to help balance times of surplus with times of shortfall, when banked RINs could be used or even borrowed against future years' production.[106] While there are some limits to RIN flexibility (no more than of 20% of the RVO in a given year can be met using RINs banked from previous years), it was sufficient to help avert a global commodity price spike, which might have otherwise occurred given the severity of the US drought.[12] A trading system has developed where RINs are purchased to meet blending obligations in a market where biofuels supply and demand varies over time and across regions. As RFS blending categories are nested, RIN values are linked allowing for more flexibility in trade and use.[104] While the current system has brought flexibility in biofuel production and consumption patterns, it created uncertainty with respect to precise biofuel targets. Some feel, therefore, that the system did not foster predictable development and commercialization of advanced biofuels.[107] Furthermore, in both the USA and Brazil, procedures for adjusting demand or setting targets are slow, cumbersome and the effectiveness of variable demand mechanisms tends to be limited in practice due to government involvement and periodic political interventions. Work remains to be done to identify the best approaches for practical variable demand mechanisms that maximize benefits to society.

An alternative program developed in the State of California, the Low Carbon Fuel Standard (LCFS), focuses on the carbon intensity of fuels, rather than on prescribed volumes. The LCFS promotes innovation, sustainability, and strict emission reductions, inducing larger shares of waste-based fuels to be generated.[108] Because the LCFS provides financial incentives that are performance-based, it allows the market and producers to determine which feedstocks are most advantageous at any point in time, balancing low cost and availability with the carbon intensity incentives offered under the program. The inherent flexibility in feedstock sourcing is consistent with the concept of variable demand.

More research is required to determine if and how mechanisms to vary demand could be employed in markets beyond the USA or Brazil. Because oversight for any program involves significant administrative costs, other opportunities are most likely to involve large producers with a considerable domestic feedstock production potential such as the EU (bioethanol made from cereals or sugar beets) Indonesia and Malaysia (biodiesel from palm oil) and Thailand (bioethanol made from cassava). The potential impact will depend on size of the non-biofuel domestic feedstock consumption,

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the relative share of the feedstocks used for biofuels, annual fluctuation of feedstock production, and price differences between food and biofuel feedstock applications. Large domestic non-biofuel feedstock markets, small output fluctuations, low biofuel feedstock shares and small price differences are expected to limit the need for, and potential effect of, variable demand policies.

What would be a viable option for governance?

Examples from Brazil and the USA suggest that biofuels policies can be developed that allow flexibility in the fulfilment of blending targets provided procedures are clear and target setting is timely and transparent. To create a stable economic environment, a market-oriented approach should be used. Governments should focus on setting and enforcing clear rules whilst not interfering with implementation. Regulation may be needed to prevent market distortion. Actual implementation is context-specific; there is no 'one size fits all' in policy. Market-oriented approaches can be effective in developed economies provided these are sufficient in size and transparent; in developing countries, markets are smaller and less likely to be effectively organized, which means that more government support may be needed. For biodiesel, for example, Indonesia can achieve that, as they have a large production of palm oil combined with a large domestic market both for cooking oil and energy. For Mozambique it will be difficult as they have small internal demand for food and for fuel.[109]

During the workshop, the following recommendations for enhancing variable demand mechanisms were formulated[25]:

- Develop policies that specifically respond to feedstock availability and price. The implementation of a temporary halt (emergency break) is recommended, which can prevent or limit potential food crises.
- Implement a buffer system that can cope with fluctuations in feedstock availability over time and space.
- Develop a banking / credit carry-forward system – bank over compliance and when necessary draw from the bank to maintain compliance.
- Implement performance-based policies with the flexibility to support local adoption and innovative solutions including better access to inputs, and access to credits and markets.
- Address market distortions, create a level playing field between various biofuels and between biofuels and biochemicals / materials. One instrument to realize this is a CO_2 tax or a renewable materials directive.
- Provide more incentives to increase crop production per hectare to close the yield gap, ensuring the regulatory and institutional context that is needed to avoid massive cropland expansion.

Conclusion

Based on recent literature and insights from international experts working in the field of food production, bioenergy policy, technology and sustainability, we find that variable demand can enhance a synergistic development of agriculture, renewable biomass feedstocks, and biofuels. However, current experience also underscores the limitations of current variable demand mechanisms in the USA and Brazil. We recommend additional research that can help society increase benefits from variable demand and identify effective approaches for integrating biofuel production with agriculture while limiting potential negative impacts on food availability and undesired changes in land cover and management. Specific research topics would:

- document lessons learned about conditions, policies, and regulations that can effectively link biofuel production with increased investments in agricultural productivity, and beneficial management of supply surpluses and shortfalls;
- develop case studies to measure and analyze actual effects of flexible biofuel markets on price volatility;
- determine the potential of intercropping and crop production systems serving multiple sectors (i.e., food, feed, fuel, fiber, materials, and chemicals), and improve the Global Yield Gap Atlas[21] to consider such integrated biomass crop production systems
- identify approaches and best practices to reduce risk to biofuel investors when incorporating variable biofuel demand policies; and
- develop proposals for standards to facilitate the implementation of international variable demand mechanisms and management of virtual feedstock reserves.

The concept of variable biofuel demand offers promising perspectives to reduce GHG emissions, improve food security, and limit environmental impacts of crop production. While theoretical opportunities for variable demand are clear, implementation faces practical and social challenges.

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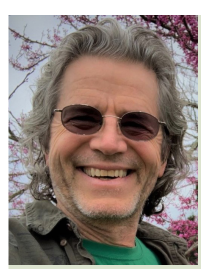

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