Crop selection for APV systems: overview of performances, potentials, and perspectives for Germany

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1. Introduction

In recent years agrophotovoltaic (APV) studies have gained major interest around the globe. APV or agrivoltaics is defined as the combination of photovoltaic panels on cropland that is installed on supporting structures allowing common agricultural practice underneath. Already proposed in 1982 [1], this dual-land use approach for food and energy was taken up by Dupraz et al. [2] in 2011 and has received increased interest from both the energy and agricultural sector since (e.g. [3], [4]). Different studies have shown APV`s ability to increase land productivity massively (e.g. [2], [7]). Considering Germany`s agricultural land area of 16.7 Mio. km², APV boasts great potential for renewable energies. Past experience with wind power and bioenergy in Germany [5] as well as other places [6] indicate though that the introduction of renewables has to be undertaken carefully to avoid major societal opposition. Thus, for the successful adoption and social acceptance of APV systems in Germany, the selection of adequate crops for cultivation in the shade of PV panels is crucial and depends largely on environmental conditions. This work is supposed to give an overview on potentials of major crops in Germany for APV systems. By contrasting the APV performances, limitations and possible APV synergies of large-scale crops compared to small-area specialized crops (perennials), this work helps to identify appropriate crops for introducing APV in Germany on a large scale.

2. Comparison of performances, limitations and synergies of staple crops and perennials from a German perspective

Germany`s farmland is split up into 70 % arable land, roughly 28.5 % grassland and a small portion of perennials [8]. The staple crops (wheat, barley, canola and maize) constitute about 70 % of the arable land. Other forms of cereals (1 Mio. ha), root crops (0.7 Mio. ha), legumes (0.5 Mio. ha), vegetables (0.15 Mio. ha) and perennials like vineyards (0.1 Mio ha.) or orchards (0.06 Mio ha) round out the picture.

Adaptability of crops grown under PV panels is the major driver in determining the potential fit for APV systems. Apple for instance as the most prevalent fruit in Germany has shown to use roughly 60 % of incident radiation [9] affirming the potential fit for APV systems. Vineyard cultivation has recently been shown to benefit from moderate shading in heat events [10]. Results from a two year trial with an APV pilot in Heggelbach, Germany demonstrate promising yield stabilizing potential for rain-fed wheat, potato and celery [11]. For an extensive review of available shading experiments on various crops (including staple crops), see [12]. However, if shading is applied solely during sensitive stages, results are only partly transferable to APV as plants adapt physiologically to prolonged shading [13]. Consequently, to draw conclusions from shading studies for APV systems, they have to be interpreted carefully. As shading effects on plant growth are quite heterogeneous even in-between varieties and thus not conclusive yet, further examination of potential plants for APV shifts to synergy effects making APV as cost-effective as possible. Although perennials occupy only a small area, expected synergistic effects are greatest in these cultures because supporting structures for plant protection (sun, wind, rain, hail) are needed anyway. By integrating these installations into the APV system, costs can be reduced and no additional land area is lost for production purposes whereas in non-perennial crops a considerable amount of land is not utilized [11]. Furthermore, minimum height requirements for the APV system with respect to common machinery in orchards or vineyards are smaller (< 3 m) compared to standard machinery in large-area farming systems (< 5 m) reducing the costs of the APV foundation even more. As staple crops are usually cultivated on larger fields, scale effects have to compensate for these disadvantages in order for them to be competitive with perennials. Albeit perennials being advantageous in regards to synergy effects, their area potential is rather small compared to staple crops (70-fold).

3. Discussion and conclusion

The results from Heggelbach show the benefits of an APV system for several major crops in Germany, highlighting yield stabilization effects. Taking this into consideration, you could argue that site selection carries greater weight than crop selection. Therefore, it is advisable for APV to focus on locations in Germany that experience droughts more frequently. However, bearing positive synergy effects for supporting structures as well as plant protection and thus economic advantages in mind, perennials like vineyards and orchards are the logical first step in introducing APV to the German market. As vineyards and orchards often are located in touristic regions, the effects of APV systems on the visual landscape have to be considered though when implementing this technology on a large scale. Although synergistic effects are less favourable in German staple crops, their wide prevalence allows for more spatial flexibility when installing APV systems, possibly reducing societal refusal. In addition, this is beneficial for decentralizing power supply. Taking aspects of future climate changes with more extreme events like heat waves into regard [14], adaptation measures as shading through APV systems will garner more attention for current common crops in Germany.

In conclusion, perennials present a great opportunity for the commercial launch of APV systems. However, imponderables like social acceptance when focusing on single crops and associated regions bear a certain risk. Hence, research should also focus on advancing economic feasibility of APV with staple crops.

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