SOLAR POWER AGRICULTURE: A NEW PARADIGM FOR ENERGY PRODUCTION

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Abstract. The present paper argues that solar power technologies, such as photovoltaic panels and wind turbines, should be regarded as a form of agriculture in the paradigm named here “solar power agriculture”. These technologies share several features with traditional agriculture, for instance the basic process of energy conversion by collecting solar light over relatively large areas. Solar power technologies and agriculture also share a dynamic resource growth curve which is s-shaped in contrast with that of non-renewable fossil resources which is bell shaped. Conventional agriculture uses solar light to produce food, textiles and other products, whereas solar power technologies mainly use light to generate electric power. Framing renewable energy within a well known and accepted paradigm, that of agriculture, leads to major advantages in terms of public image, with the consequent unlocking of the financial resources needed to increase the use of renewable resources. The concept of solar power agriculture provides a bridge between the present situation in which renewable play a marginal role in the world’s energy production to a future situation when renewables will instead play a major role.

Keywords Solar energy, power generation, agriculture

1. INTRODUCTION

The world is not running out of fossil fuels, but progressive depletion is making these fuels expensive as the result of factors which include increasing direct costs (e.g. the need to exploit smaller fields) and increasing external costs related, for instance, to the greenhouse effect generated by the products of combustion. The rise of these costs will cause the production of fossil fuels to reach a peak at some point in time and subsequently to decline as extraction becomes progressively less and less convenient in economic terms. Some projections (1-4) indicate that the peak for crude oil production could take place within the first decade of the 21st century, to be followed by the other fossil fuels peaking in later decades.

The production curve of a mineral resource is often described as "bell shaped" (5). In contrast, the curve for agricultural production is, in principle, s-shaped, i.e. it reaches a plateau when all productive land is exploited. Agriculture is sustainable, at least in theory. Historically, both soil and water may turn out to be a non-renewable commodity when misused (6,7), however it is at least a physical possibility for agricultural societies to reach a stable state.

The subject that the present paper addresses is how fossil fuels can be replaced as a source of energy using renewable solar technologies in the "agricultural paradigm", that is in order to abandon the "bell shaped" curve and reach, instead, a plateau of production at levels comparable to the present values. In this approach, called here "Solar Power Agriculture", energy, and in particular electric power, produced on agricultural lands is considered as just another form of agricultural product, to be approached with the same social and economic approaches which are commonplace for conventional agriculture.

Several previous reports (e.g. 8-16) have discussed the ultimate limits of solar technologies in terms of land requirement. These studies arrived to the conclusion that a fraction of the earth's equatorial deserts would be sufficient to provide abundant energy for humankind's needs. However, large scale renewable energy plants in deserts do not appear to be on the verge of materializing. The main problem appears to be the need to attract the huge investments needed, both for the plants and for the related energy vectoring system.

Here, a different approach is considered on the basis of the idea that renewable energy can to make significant inroads in power production only if its introduction is gradual and it starts from a relatively small scale. This approach leads to the idea of embedding solar plants within areas used for conventional agriculture. It is an approach, in fact, that has already been tested for wind energy in countries such as Denmark and Germany. Obviously, the possibility of expanding this strategy to obtain a significant fraction of the worldwide energy needs depends on a number of factors:

1. *Technological factors*: can renewables produce enough energy for the needs of humankind without competing with conventional agriculture for land needed for food production?
2. *Cost*: Even when embedded in conventional agricultural production, won't renewable energies remain too expensive?
3. *Public opinion*. Can the relatively large extension of land needed for solar energy be made acceptable to the public?

The present paper will show that the answer to all these question is, in principle, positive and that the concept of solar power agiculture has a strong potential in order to speed up and favor the introduction of solar renewable technologies in the world.

2. Technological factors

Human beings have been exploiting solar energy for their needs since the time when agriculture was first developed, about 10,000 years ago. As a technology, agriculture was hugely successful and in time it diversified and expanded until, at present, most of the land "potentially suitable for agriculture" on the planet, about 130 million km^2, (17,18) is exploited for human needs. The fraction of this land which is exploited for food production, i.e. the sum of pasture land and arable land corresponds to approximately 50 million km^2, that is about 38% of the total (17,18)

Agriculture uses solar energy to carry out chemical synthesis, in turn based on photosynthesis, a biochemical process which uses solar light as the source of energy necessary to synthetize carbohydrates from water and carbon dioxide. Further stages of the biochemical process can produce a variety of organic substances. Mainly, agriculture is used to produce foodstuff and fiber for textiles. Traditionally, agricultural biomass has been also used as energy source for residential heating but in recent times it is increasingly exploited to produce electric power and, in some cases, fuel for traction.

Other physical and chemical processes to exploit solar light for human use have been known for a long time but the large scale development of what we call “renewable energy technologies“, started only during the first decades of the 20th century with hydropower plants. The last decades of the 20th century saw the extensive development of the technologies which go under the name of “new renewables”. Among these, we can define as “solar direct” methods those which collect and exploit solar light: mainly photovoltaic (PV) and solar concentration. We may define as “solar indirect” methods those which exploit the effect of the solar light in heating the atmosphere or the ocean: wind power, small hydropower (SHP), wave, ocean currents, and others. There exist also renewable technologies which are not based on solar energy, i.e. geothermal and tidal which may play an important role in the future but which will not be considered in detail here as they can’t be framed within the “agricultural” paradigm.

The energy needs of humankind will vary in the future depending on population and on the human lifestyle. The present work does not attempt to address projections for the future growth of population, nor the need of equilibrating the energy use by different fraction of the population. However, considering the slowdown of population growth observed during the past decades, most authors indicate that a stabilization of the world population might take place around mid 21st century for numbers not much higher than the present ones. Therefore, an “order of magnitude” estimation of the energy needed can be obtained examining the amount of energy used nowadays.

The parameter to be examined here is the “total final consumption” (TFC). This is a better parameter to consider in the present context than the other common one, “Total Primary Energy Supply” (TPES), since renewables normally provide immediately exploitable energy in the form of electric power. The world TFC is reported to be $8.4\text{x}10^7$ GWh/year (20) of which electric power is about $1\text{x}10^7$ GWh/year. The OECD countries have access to 53.5% of the world TFC (20) for a population of 17% of the world total.

The amount of solar energy that reaches the surface of the earth is commonly given as $1\text{x}10^{12}$ GWh/year (see. e.g. ref. 16): a value more than ten thousand times larger that the present TFC. The fraction of this energy which arrives on the planetary land surface is about $3\text{x}10^{11}$

GWh/year. In addition, we can roughly estimate the wind energy generated by solar irradiation as ca. 2% of the total solar energy arriving on the earth surface (16), that is about $2x10^{10}$ GWh/year, again very large in comparison to the target. The energy associated with the global water flow generated by thermal effects is very difficult to estimate, but it is another very large amount.

These data are listed in table 1, together with two more data for comparison: the amount of the total biomass produced every year on the planet, some $2x10^{11}$ tons/year, or $1x10^{9}$ GWh/year (21) and the total human metabolic requirement (21).

Table 1:

Energy type	*GWh/year*
Human total metabolic energy requirement (present)	**$5x10^{6}$**
World total electric power generation (present)	**$1x10^{7}$**
World total final consumption, TFC (present)	**$8x10^{7}$**
World total biomass produced	**$1x10^{9}$**
Solar energy arriving on the earth's land surface	**$3x10^{11}$**
Total solar energy arriving on the earth's surface	**$1x10^{12}$**

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The actual possibility of exploiting the large amount of solar energy arriving on the earth surface depend on the efficiency of the technology used. Furthermore, we have to consider the *quality* of the energy produced by solar technologies and not just its amount. Passive solar collectors, for instance, may be very efficient in terms of producing residential heating, but the low temperature heat produced is not suitable for power production.

Most renewable technologies (e.g. photovoltaics and wind turbines) generate high quality energy in the form of electric power and can therefore be used for the direct replacement of fossil fuels in power production. It is also always possible to use high grade energy to efficiently produce low grade energy, such as domestic heating. Regarding vehicle fuels, at present hydrogen, which can produced from electricity and water, appears to be a possible choice as replacement for fossil fuels. A different situation exists with biomass, which can be used to generate electricity but also burned to obtain heat or processed to obtain liquid fuels. In practice, for the purpose of comparison, in the present discussion it can be simply assumed that the energy output of renewables in the form of electric power can be used to replace all the forms of energy that compose the world TFC of today. This approach has been used, among others by Pimentel (15)

This said, we can calculate the fraction of land area (or "footprint") needed to generate the amount of energy needed by humankind by renewable technologies. In general, solar irradiation on populated lands ranges from a minimum of ca. 900 kWh/m^2/year (e.g. northern Europe) to values of the order of 2200 kWh/m^2/year in subtropical regions, with even higher values in equatorial areas such as the Sahara. An approximate worldwide average value for populated areas could be taken as ca. 1500 kWh/m^2/year. The OECD countries tend to be located somewhat farther away from the equator, so that an average value in this case should be lower.

Commercial photovoltaic panels have an efficiency that today can routinely reach 14%. Experimental PV cells and solar concentration plants may do significantly better. The efficiency of the power delivered to end users by this kind of plants can be reasonably considered in the 5%-10% range. In terms of land use, with such efficiencies, solar direct plants can bring to the end user 60-120 kWh/m^2/year in medium latitude areas (1200 kWh/m^2/year). As an order of magnitude estimation, it is possible to consider an average value of 100 kWh/m^2/year for the power delivered to end users.

In the case of solar indirect technologies, it is not possible to define a land requirement in the same way as for photovoltaics. Wind turbines must be spaced at a certain distance from each other, but most of the land occupied remains available for agricultural use. The physical footprint of a wind turbine may be estimated to correspond to a land use of about a factor 100 smaller than PV panels for the same delivered power. Of course, offshore wind turbines do not occupy any land area, and the same is true for SHP plants and for all the schemes which use wave power or oceanic currents.

Finally, as a direct solar technology, biomass is relatively inefficient. The upper limit of photosynthesis efficiency at the molecular level is estimated as 6% by Tiezzi (21) and as 4.5% by Patzek (22). In practice, the efficiency of biomass production in plant organisms is much lower. From the data of table 1, it can be calculated that the "planetary efficiency" for biomass production is about 0.1%.

In specific cases, the efficiency can be higher. Patzek (22) reports a calculation on the average potato yield in England where the photosynthesis efficiency turns out to be 0.4%. According to Tiezzi (21) crops may have yields of the order of 1%, but only at the cost of extensive use of irrigation and of fertilizers derived from fossil fuels. Another source (23) reports that some ecosystems, such as tropical forests, can reach efficiencies of conversion higher than 1% whereas crops cultivation has an average efficiency of ca. 0.3%. Taking into account the need of using a thermal engine to produce power, the sustainable efficiency of biomass as a source of electric power cannot be considered as higher than ca. 0.1%, again as an order of magnitude estimation. Obviously, the generation of electric power is not the best energetic use for biomass, but this value will be retained as a means of comparing biomass conversion with other energy sources.

A further important parameter affecting land use is the energy payback ratio (EPR). This parameter can be defined as the total amount of output energy produced by the plant over its lifetime divided by the input energy, that is the energy required to build, maintain, fuel (if needed) and eventually dismantle the plant, as well as energy needed for vectoring the energy produced to end users (see e.g. ref. 15). The concept of EPR can be expanded to include also the external costs (e.g. greenhouse gases produced) of the plant, measured – again – in terms of energy. This parameter defines the "ecological footprint" (EF) of an energy producing plant, which is larger (and may be much larger) than the actual footprint of the plant. For instance, for fossil fueled energy plants, the EF is large because it is calculated taking into account the area of forest needed to remove the amount of CO_2 generated in the combustion of the fuels (24).

On the basis of the concept of EPR, the Ecological Footprint (EF) of a renewable technology can expressed in units of area needed to provide a certain yearly output of energy, taking into account the area needed for the input energy, obtained using the same technology and averaged for the same period. Simple considerations lead to express the EF as a function of the actual footprint (AF) as:

$$EF = AF \frac{EPR}{EPR - 1}$$

The EPR is a difficult parameter to calculate and the estimates reported in the literature are widely variable. Some significant values for the technologies considered here are listed in the following table. For comparison, a giant oil field in its prime is reported to have an EPR of ca. 30-50, whereas the EPR for partially depleted and/or smaller oil fields may be around 10 or lower (25).

Table 2

Technology	**EPR**	**EF/AF**	**Ref.**
Bioethanol	1.25	5	*26*
Biomass	3	1.5	*15*
PV	9	1.12	*15, 27*
PV	17	1.06	*27*
Wind	23	1.05	*28*

The values of table 2 are to be considered as estimations only, however they do indicate that for the "new renewables" (mainly PV and wind) the EPR effect the EF/AF ratio as of the order of 10% or less and therefore can be considered to lie within the uncertainty of the estimation of the needed land area. For biomass, the area correction for a value EF/AF ratio of 1.5 cannot be neglected, but it must also be taken into account that the EPR calculated by Pimentel (15) includes the loss due to the transformation of heat to electric power. Therefore, the approximate value of "0.1%" calculated before can be retained since it already took into account the this inefficiency factor. It is to be stressed that this biomass is intended to be mainly harvested from natural forests. Crops or other agricultural products make little sense as sustainable energy sources because of the extensive need for fertilizers, irrigation, etc which makes their EPR close to one or even lower than one as reported by Pimentel (29) for bio-ethanol.

The last important parameter to be considered here is the need of energy storage for intermittent sources such as photovoltaic and wind power plants. It is known that when the amount of energy produced by intermittent sources exceeds ca. 20% of the total grid power, it becomes difficult to control the energy imput to the grid without some kind of energy storage. There exist a large number of methods for electrical energy storage, several still in the development stage (e.g. hydrogen coupled with fuel cells) others are possible only as large scale solution (e.g. pumped storage). For the present land area estimation, it will suffice to note that storage does not involve large areas and so it does not need to be considered here.

Once these data are available, the simplest approach, is to examine the land use for each kind of technology and from that calculate the extent of planetary land needed to generate, for instance, an amount of energy in the form of electric power equal to the present TFC. The following table summarizes the considerations developed so far

Table 3

Method	Approx. efficiency of light conversion (ratio of incident solar energy to electric power delivered to users)	Order of magnitude deliverable power per area occupied (footprint) for an irradiation of 1200 kWh/m^2/year. (kWh/m^2/year)
Organic biomass	**~ 0.1%**	**~1**
Solar direct (PV or solar thermoelectric)	**5%-10%**	**~ 100**
Solar indirect (wind)	**n.a.**	**~ 10000 (on suitable sites only)**

At this point, we may proceed with embedding the data found so far within the concept of agriculture. That means to estimate what fraction of the land is needed to generate energy comparable to the present day use. The relevant numbers here are listed in table 4 (data from refs. 17 and 29).

Table 4

	Millions square km
Land "potentially suitable for agriculture"	**130**
Land used for food production	**50**
Arable land (crops production)	**1.5**

There is a certain degree of uncertainty in these data (18), but the values reported here can be considered as prudent estimates. The concept of "land used for food production" is the sum of the arable land plus the grassland used for pasture. It is reasonably safe to assume in both cases the land is accessible by human beings and equipment, that it exists in human-compatible conditions of climate and temperature. Hence this area is also suitable for setting up energy producing plants.

From these data, it is possible to estimate the extents of land required for two targets taken as the energy equivalent to prenent value of world electric power generation (target 1) and equivalent to present value of world TFC. The results are listed in table 5.

Table 5

	Land area needed as percentage of land used for food production (50x10^6 Km^2)	
Technology	**Percent area for Target 1** Energy equivalent to present value of world electricity generation (1x10^7 GWh/year)	**Percent Area for Target 2** Energy equivalent to present value of world TFC (8x10^7 GWh/year)
BIOMASS conversion to electric power	**21%**	**>100%**
SOLAR DIRECT conversion (PV or solar concentration)	**0.2%**	**1.5%**
SOLAR INDIRECT conversion (wind)	**0.003%**	**0.03%**

The values reported in table 5 are, obviously, just orders of magnitude and are also to be considered as conservative. The fraction of land needed for the stated targets could become smaller for technological improvements and also taking account that a considerable fraction of the plants could be placed in areas which are not “agricultural land”, for instance offshore.

The data, anyway, lead to the conclusion that both solar direct and solar indirect plants embedded in agricultural land would have a very small impact on agricultural production even for the relatively ambitious targets outlined above. Indeed, the human metabolic requirement of energy is only 5x10^6 GWh/year and with the known efficiency of the best crops it could be managed in just a few percent of the world land area. The impact of energy plants on agriculture would be, therefore, smaller than that of phenomena such as erosion and soil degradation.

It is also worth comparing the surface needed for energy production with that of urban areas. Here, the data available are very uncertain. Kitajma (30) estimates the fraction of "urban land" as ca. 2% whereas Goldsmith (31) reports data which indicate that the fraction of land covered with "permanent structures" may be as high as ca. 15%. The large discrepancy among these values is probably due to differences in the definition of "urban land". However, Kitajima's estimation, compared with the data of table 3, indicates that at the the land area needed to provide a town with sufficient energy is of the same order of magnitude as the urban area. In other words, a town should dedicate a land area of extent approximately equal to the area of the town itself to the production of energy. Micro-production of energy at the level of single roofs is a possible solution, but a much easier approach is to disperse this production over the agricultural land surrounding the town. There exist very large urban spreads in the world where this approach may be difficult, but in most OECD countries towns are surrounded by agricultural areas much larger than the towns themselves.

It may also be remarked that it may be possible to make even solar direct technologies compatible with organic agriculture occupying the same areas. Right now, the shadow of a solar plant (photovoltaic or thermoelectric) makes it impossible to cultivate the area underneath. However, photosynthesis uses only a fraction of the solar light spectrum and solar direct plants could be modified to let energy pass through in the right wavelengths only. The mirrors of a solar concentrating plant, for instance, could be coated in such a way to reflect only the part the spectrum not used by photosynthesis, letting instead pass the rest. The efficiency of the solar plant would be lowered, but it would be possible to cultivate the area underneath. This technology is probably unnecessary at present because of the small fraction of area needed by solar plants, but it is mentioned here as a possibility for the future.

3. Costs

Estimations of the costs of renewable energy are common in the literature, a review can be found, for instance, in a recent IEA report (8). In most of the studies published so far, the calculations arrive to values that favor fossil fueled plants over renewables. In general, electric power generated by wind turbines is only marginally more expensive than that generated by fossil fuels. For photovoltaic panels, the gap is large, of approximately a factor 5 (see, for instance, ref. 10).

The "solar power agriculture" paradigm offers a way to look at the financial support for renewables which goes beyond the cost calculations reported in the literature. The misleading factor of these calculations lies in the fact of producing a single, static number. However, the cost of energy is dynamic and it varies over the whole lifetime of a plant which, for the case of renewable plants may be very long, typically of a few decades. We saw in the previous section that the "new renewables" produce a positive, and often highly positive, energy payback ratio (EPR). Since energy is worth money, there follows that the financial return from these technologies will be positive in the long run. It may argued on whether other investments will produce a quicker return, but not on the fact that the money and resources placed into the deployment of renewable energy plants will be, eventually, paid back and will subsequently produce a profit. A case could be made that renewables are not only an effective investment but also the safest possible investment since they produce a commodity, energy, which is the basis of human civilization and hence will never suffer market crashes.

However, it doesn't appear that investors have picked up yet the potential of renewable energy. This may be due to the bad image of renewables which still lingers in the press and in the public opinion. In this respect, it may be worth citing here as an example an article by J. Dvorak (32): "People still equate photovoltaics with the hippy-dippy 1970s. A recent article in the New York Times showed some hippies in Ukiah, California, with a solar panel outside their yurt-like home with a sod-covered roof. Presumably, the solar panel was used to power a lava lamp.“

Apparently, the promotion of renewable energy done so far has been all wrong with the emphasis made on the concept that renewable energy is something "soft" as opposed to fossil fuels which, somehow, are "hard. Switching to "soft" energy, apparently, would change our way of living, maybe carrying all of us to the aquarian age, to a higher state of consciousness or something like that. It isn't clear how the kWh at a domestic outlet can be defined "hard" or "soft" and anyway these concepts don't go well with hard nosed investors who are more likely to think in terms of financial returns rather than in terms of holistic happiness.

However, once we move to the paradigm of "agriculture", the image of renewables can be much improved by placing renewable energy within a context which is known to be reliable, solid, and effective. Maybe agriculture never provided such a rapid return on investments as startup companies from silicon valley, but everybody understands (or should understand) that we can't eat silicon. So, there is a logic in investing in agriculture and the point is to determine who should be interested in doing an investment that privileges safety over speed and which also has a certain degree of "ethical" value. Here is where the "agriculture paradigm" as opposed to the "industrial paradigm" can be most useful.

As long as energy production is managed by power utilities, as it is the case today, energy is produced within the "industrial paradigm" since power utilities are industrial companies which have a tradition of generating energy from the combustion of fossil fuels. In the industrial paradigm, the capital is provided by shareholders and companies will normally choose the road that leads to the fastest return on investments. In "solar power agriculture", however, the situation is different and the focus moves from capital to land. The question that a stock market investor asks is "how can I increase the value of the *capital* I own?" while the question that a farmer or agricultural operator asks is "how can I increase the value of the *land* I own?" The answer to the latter question is to produce something on the land: it may be crops, it may be wine, it maybe wood, it may also be electric power in the paradigm if solar power agriculture.

Large financial resources could be unlocked and utilized for the diffusion of renewable energy as soon as the concept of solar power agriculture becomes an accepted paradigm. For instance, the budget of the European Union for "rural development" in the period 2000-2006 is of approximately 50 billion euros. It is worth noting that in the 2003 document describing the EU agricultural policies (33), the world "energy" is not even mentioned, although there is one picture showing 19th century windmills. If governments realize that agriculture can be supported in an effective manner by means of the concept of solar power agriculture, part of these resources can be utilized for the diffusion of solar energy in farmlands; this benefits not only farmers, but all the sectors of society.

It remains to be consider how fast renewable energy could develop in order to cover the targets outlined here. This depends on the amount of financial resources that can be reasonably allocated to renewables and that may be estimated from the historical record. During the 1990-2000 decade wind power grew at an average rate of 22.4% per year and photovoltaic of 28.9% in the countries belonging to the OECD (Organization for Economical Cooperation and Development) (8). According to the BP statistical energy review (34) the growth of wind power worldwide was of 29% from 2001 to 2002, with the wind share of total global electricity supply increasing four-fold since 1996, to 0.4% in 2002. In those countries where wind technology can be considered as "mature", the data (35) growth rates higher than 20% have been observed over at least one decade as for instance in Denmark (22.0% yearly) and in Germany (62.9% yearly). As a comparison, the highest rate of growth of crude oil production was 7% yearly for the period from 1930 to 1971 (1).

At a yearly growth rate of 20% and starting with 0.5% of the present supply, renewables could grow to produce the equivalent of the electricity produced today by fossil fuels in 30 years. This is, obviously, just an order of magnitude estimation. However it shows that renewables have the potential to replace fossil fuels in times comparable to those estimated for their depletion to set in at levels such as to make extraction uneconomical.

4. Public acceptance and environmental concerns

Opinion polls show that most people are, theoretically, favorable to renewable energy (e.g. 36). However, when it is question of turning ideas into practice and actually build plants, the public opinion may not remain as favorable as opinion polls claim it to be. Basically, people object to renewable energies for two reasons:

1. Renewable energies are seen as ineffective, that is they are not taken seriously a source of power. This concept leads

to the related opinion that money and resources should be better spent in energy conservation measures.

2. Renewable energies are seen as polluting, not in the same way as fossil fuels or nuclear plants, but still causing visual pollution, damaging wildlife, producing noise, etc.

These two arguments are closely linked to each other. Surely, people would be much more willing to accept the noise and the visual pollution of renewable plants if they were convinced that they are a real option to get rid of fossil fuels. Evidently, this is not the case since in recent times a remarkable backlash has been observed against wind power (e.g. ref. 37). The negative public attitude is not limited to wind turbines only. Mini-hydro plants are also accused to kill fish (8) and photovoltaic power is accused of using up too much land (see, e.g. ref. 38).

The emergence of such negative attitudes towards renewable plants is often related to policy mistakes, in this case in the way the new plants are proposed. Local communities often resent being invaded by power utilities with their gigantic wind towers. People feel (in most cases, correctly) that the value of their property will be reduced by the presence of large and visible energy plants in the vicinity. In these conditions, local communities cannot be blamed for opposing renewable plants.

Here, the paradigm of "solar power agriculture" can reduce public opposition to renewable energies. By linking the new renewables with a well known and accepted technology such as agriculture, the gain in image is impressive. Solar power technologies, such as wind turbines and PV panels, cease to be seen as toys for hippies or bird-killing machines but become part of a respected and reliable production system which has fed mankind for some ten thousand years and is still feeding 6 billion people on the earth. If, as it is the case, solar power agriculture is just another form of conventional agriculture, then it shares with it the same sturdiness, reliability, and social value.

At the same time, the visual impact of the new renewables is considerably reduced in relative terms when it is looked at in the context of the impact of traditional agriculture. It may be argued that no activity of mankind on earth has had a more important impact than agriculture. Indeed, with about 40% of the land area used for food production, and a comparable fraction used for fiber and biomass production, we can say that traditional agriculture didn't just have an impact on the environment, it radically changed the face of the planet. In many cases, actually, agriculture has been devastating for the environment, leading to irreversible salinization of desertification of large areas (7). In comparison, turning less than 1% of the land from conventional agriculture and/or forestry to solar power agriculture represent no major ecological impact.

5. Conclusion and perspectives for the future.

The paradigm of "solar power agriculture" outlined here falls within some well known and accepted paradigms of agriculture and it goes one step beyond the idea that renewables are useful for supplying isolated areas with energy. Here, it is the opposite case: the existing power lines can be used for carrying the rurally produced electricity to towns and industrial centers at little or no additional costs. Carrying their products to town is what the rural world has been doing during the past 10,000 years or so.

The concept of "solar power agriculture" permits to approach the problem of introducing renewable energy in the world supply in a completely different way than the presently accepted industrial paradigm. The use of renewables for isolated or remote areas is probably reaching saturation whereas the idea of placing large solar plants in desertic areas has not materialized yet for the high investments needed and for the lack of a suitable infrastructure for transporting the energy produced. However, once electricity (or other forms of energy) are placed in the same range of products as agricultural products, we immediately set a path of growth which is gradual, economically sound, requires low investments, and which can be put into practice in OECD countries without revolutionary changes.

The present work has calculated that the fraction of land needed for present-day renewable technology to provide the world with an amount of energy comparable to the energy produced by fossil fuels would have only a minimal impact on food and textile agricultural production. The experience of the past decade shows that renewable energy production can grow at a yearly rate higher than 20%, much larger than the present trends of increase in energy production (around

2% year). If these trends could be maintained, even ambitious targets such as the complete replacement of fossil fuels by renewables are not impossible in less than one century.

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