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ITALIAN NATIONAL AGENCY
FOR NEW TECHNOLOGIES, ENERGY AND
SUSTAINABLE ECONOMIC DEVELOPMENT

Opportunities for new techs

Energy transition: an analysis of agrivoltaic utilities suitability in terms of Levelized Cost of Electric Energy.

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Italian National Agency for New Technologies, Energy and Sustainable Economic Development

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Who is speaking?

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- **Girolamo Di Francia** is research director in ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development).
- Head of the ENEA Photovoltaic and Sensor Applications Laboratory;
- Qualified as Full Professor of Applied Physics;
- Independent expert-supervisor for the European Union;
- Indipendent expert-supervisor for the Italian Minister for Research and Education;
- Member of the European Technology Photovoltaic Platform;
- Coordination of several, national and european, research projects;
- >220 papers in international journals (SCOPUS h index = 31); 250 communications to national and international congresses.
- 11 patents:
- Steering Committee of the Italian Association Sensors and Microsystems (AISEM) since 2005;
- Author of some popular scientific articles appeared on widely diffused magazines and journals (Le Scienze, La Repubblica, Science).

The problem: what we are talking about?

1) PHOTOVOLTAIC

2) CONCERN about the land consumption by the PV source

The problem: Italy as a case study

1) In 2022, in Italy, electric energy consumption has represented roughly 25% of the global energy consumption.

2) According to TERNA (the national TNO) in 2022 the electric energy consumption totalled about 317 TWh.

The problem: Italy as a case study

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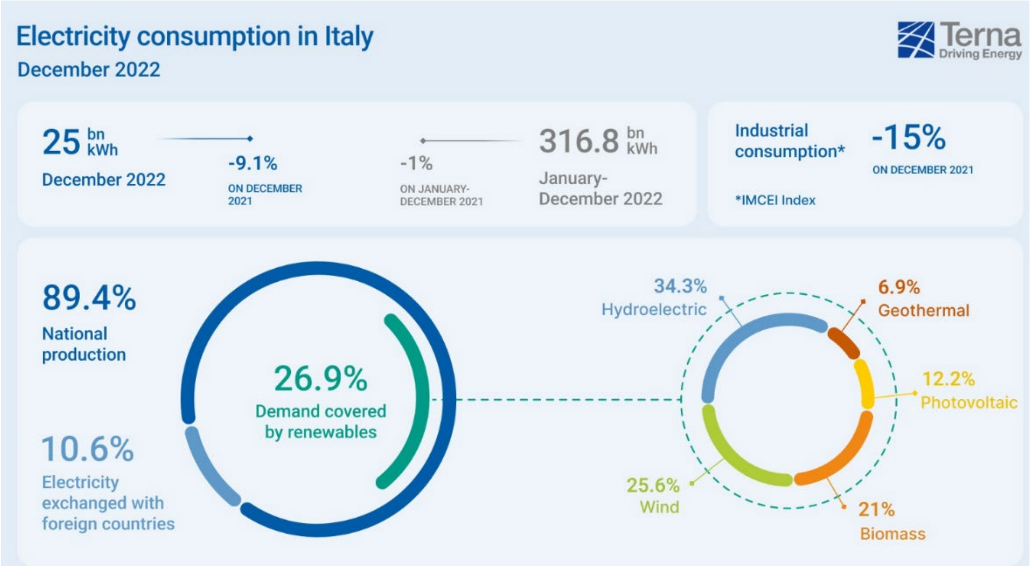
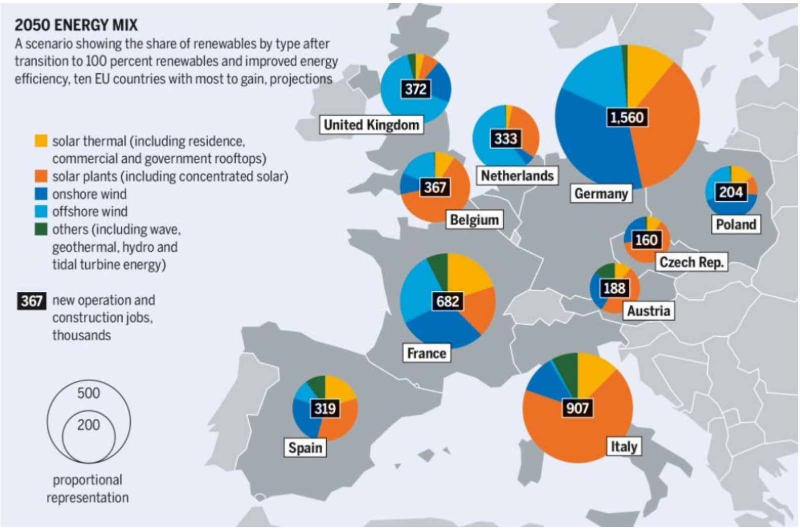
3) Photovoltaic in Italy 2022: <4% or <16 TWh



If all the Italian energy needs were turned into electricity needs, that would mean a demand of roughly 1200 TWh.

The problem: EU energy roadmap* 2050

1) The energy transition mix 2050 in EU



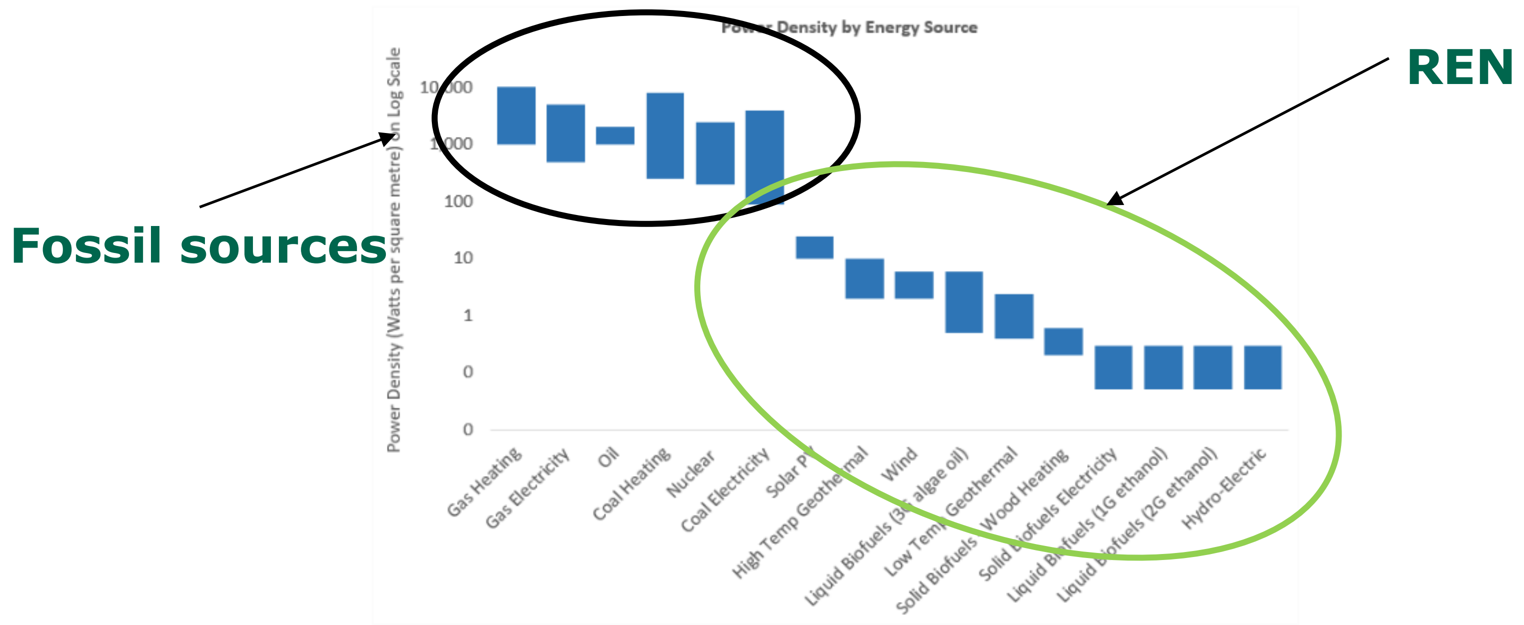
2) Assuming for Italy a 40% PV share this means ≈ 500 TWh; and since in Italy 1250kWh/kWp

≈ <u>400 GWp have to be installed up to 2050</u>

That means: 400 bEUR in 25 years or 16 bEUR/yr for the next 25 years and 2 bEUR/yr in terms of traded electricity;

*https://energy.ec.europa.eu/system/files/2014-10/roadmap2050_ia_20120430_en_0.pdf

The problem: the energy density



	POWER DENSITY (W/m2)
Photovoltaic	**80**
Wind	**10**
Hydro	**0,1**

The energy density problem (or what about the land use?)

PV: how much land is used?

Assuming: 50% residential

and 50% utilities

RESULTS: in ITALY

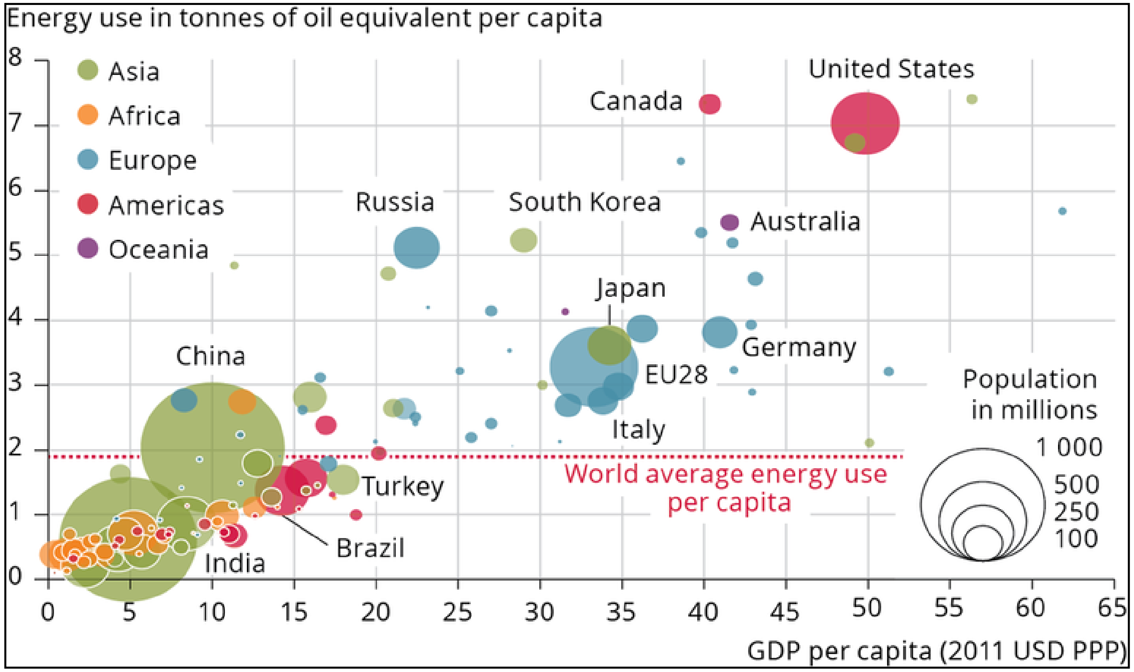
1) globally 200,000 ha of arable lands would be necessary;
2) that would mean 1.5% of all the arable land;
3) and 10% of the whole arable land so far abandoned;
4) and two times the arable land that is lost every year in Italy;

The problem: Conclusions

1) There is <u>hardly a land consumption problem</u>

but

2) there still can be <u>an ethical and moral problem</u>:



Pro-capita energy use vs. pro capita GDP

The true question is: is it reasonable to use agricultural land for energy production, that is for a commodity mostly required by wealthy countries, instead than for food, when there is so many people in the world suffering famine?

Agrivoltaic can be the answer

Photo courtesy granted under creative commons license by: Stacey Kihiu/ICRAF.(Latia Agribusiness solutions, 2022)

Agrivoltaic is it feasible?

a) Is it technically possible?

b) What are the costs involved?

c) What are the risks (if any)?

Agrivoltaic: a) technically possible?

Japan, 2014

Germany, 2018

US, 2023

Agrivoltaic: b) costs

LCOE is the Levelized Cost of Energy

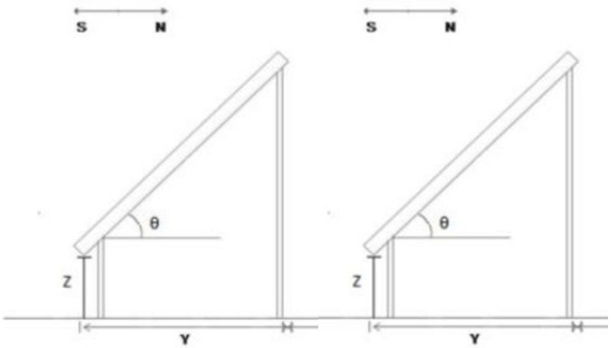
$$LCOE = \frac{(Plant\ costs\ along\ its\ whole\ lifetime)}{(Energy\ Yield\ along\ its\ whole\ lifetime)}$$

$$LCOE = \frac{\left(CAPEX_{PV} + \sum\left[\frac{OPEX_{PV}(t)}{(1+WACC_{nom})^t}\right] + \frac{InvRepl}{(1+WACC_{nom})^{N/2}} - \frac{ResVal}{(1+WACC_{nom})^N}\right)}{\sum\left[\frac{Yield(0)\times(1-d)^t}{(1-WACC_{real})^t}\right]}$$

$$WACC_{real} = \left[\frac{(1+WACC_{nom})}{(1+i)}\right] - 1$$

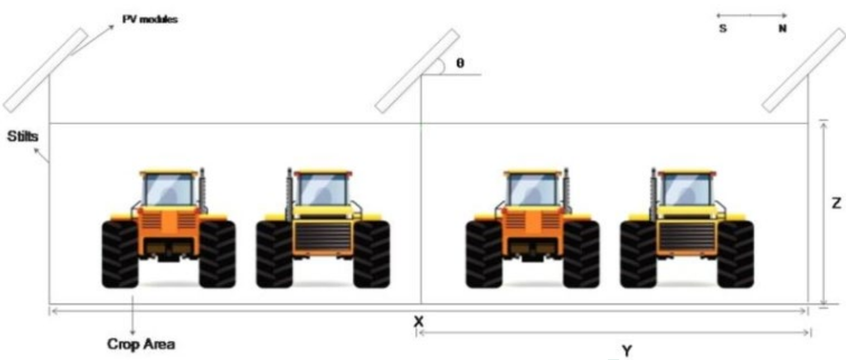
Ref. Vartiainen E.; et al. Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility scale PV levelised cost of electricity, Progress in photovoltaics: research and applications, **2020**, Volume 28, pp. 439-453.

Agrivoltaic: plants investigated



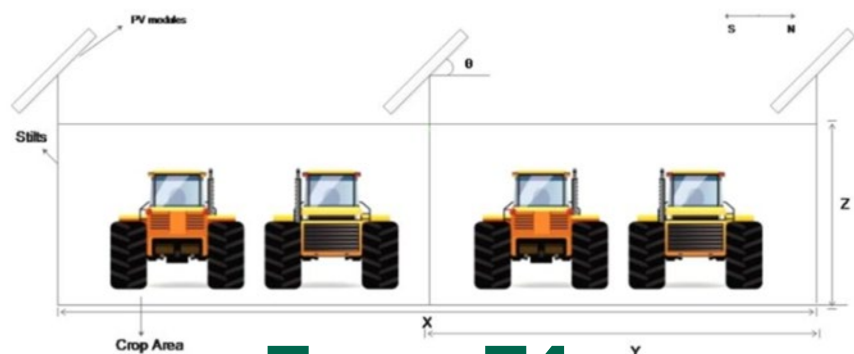
Type, T0

Type, T1



Type, T2 and T3

Ǝ: Minimum cultivated area



Type, T4

No concrete foundations;
With a farmer;

Agrivoltaic: plants investigated

The different types of agrivoltaic systems investigated in this work are classified according to the MASE guidelines criteria.

Criteria	A1	A2	B1a	B1b	B2	MMH	D	E	With agricultural entrepreneur	Absence of concrete foundations	Name
Type 0 (T0)	No	No	No	No	No	No	No	No	No	No	Photovoltaic installed in agricultural and non-agricultural areas.
Type I (T1)	>70%	<30%	No	No	No	No	No	No	No	No	Basic agrivoltaic
Type II (T2)	>70%	<40%	Yes	Yes	Yes	Yes*	Yes	Yes	No	No	Advanced agrivoltaics
Type III (T3)	>70%	No	Yes	Yes	Yes	Yes*	Yes	Yes	No	No	Advanced agrivoltaics similar to T2, without reference to LAOR
Type IV (T4)	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Advanced agrivoltaics PNRR

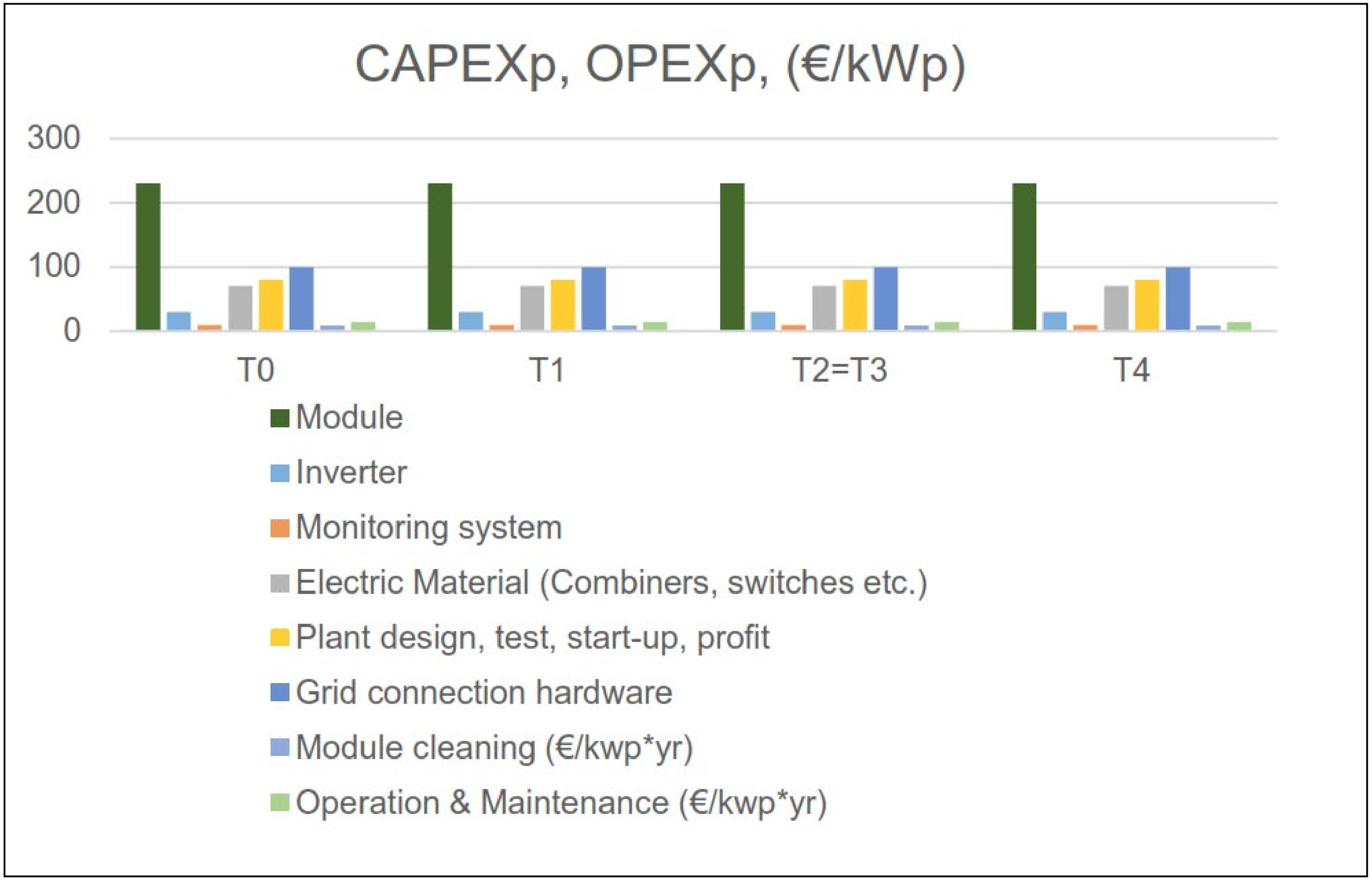
A.1) Minimum cultivated area larger than 70 % of the total land area;
A.2) LAOR (Land Occupation Ratio), that is the ratio between the surface of the modules to the total land area) less than 40%;
B.1a) Preserving the yield of agricultural and/or pastoral activity for the plot of land considered for APV installation (in EUR/ha or EUR/LU-Unit of Adult Livestock);
B.1b) Preserving the continuity of agricultural and pastoral activity;
B.2) The electrical producibility of the agrivoltaic plant has to be 60% higher than a standard PV plant;
C) A minimum ground - PV modules distance, MMH, has to be respected (2.1 m agricultural activity, 1.3 m pastoralism);
D) The installation of monitoring systems to verify water saving, agricultural productivity, continuity of agricultural activity have to be considered;
E) The implementation of advanced monitoring techniques to verify the recovery of soil fertility, microclimate effects, resilience to climate changes have to be implemented.

Agrivoltaic: cost of investigated plants

1 MW PV plant	T0	T1	T2=T3	T4
P (kW)	1000	1000	1000	1000
Plant neat surface (module 400 w, 2x1 m^2, inclination 35° , Set Back Ratio =3 m), ha	1,2	1,3600	1,2	1,2
Plant total surface (including service areas), ha	1,25	1,4300	1,25	1,25
Power plant density, W/m^2	80	70	80	80
Module number	2500	2500	2500	2500
Module total surface, m^2	5000	5000	5000	5000
Ground module projection, m^2	4075	4075	4075	4075
LAOR	NA	0,4000	0	0
Total surface (to take LAOR into account according to the guidelines), ha	NA	1,43	1,2	1,2
Plot of land perimeter (assuming a square plant), m	440	480	440	440

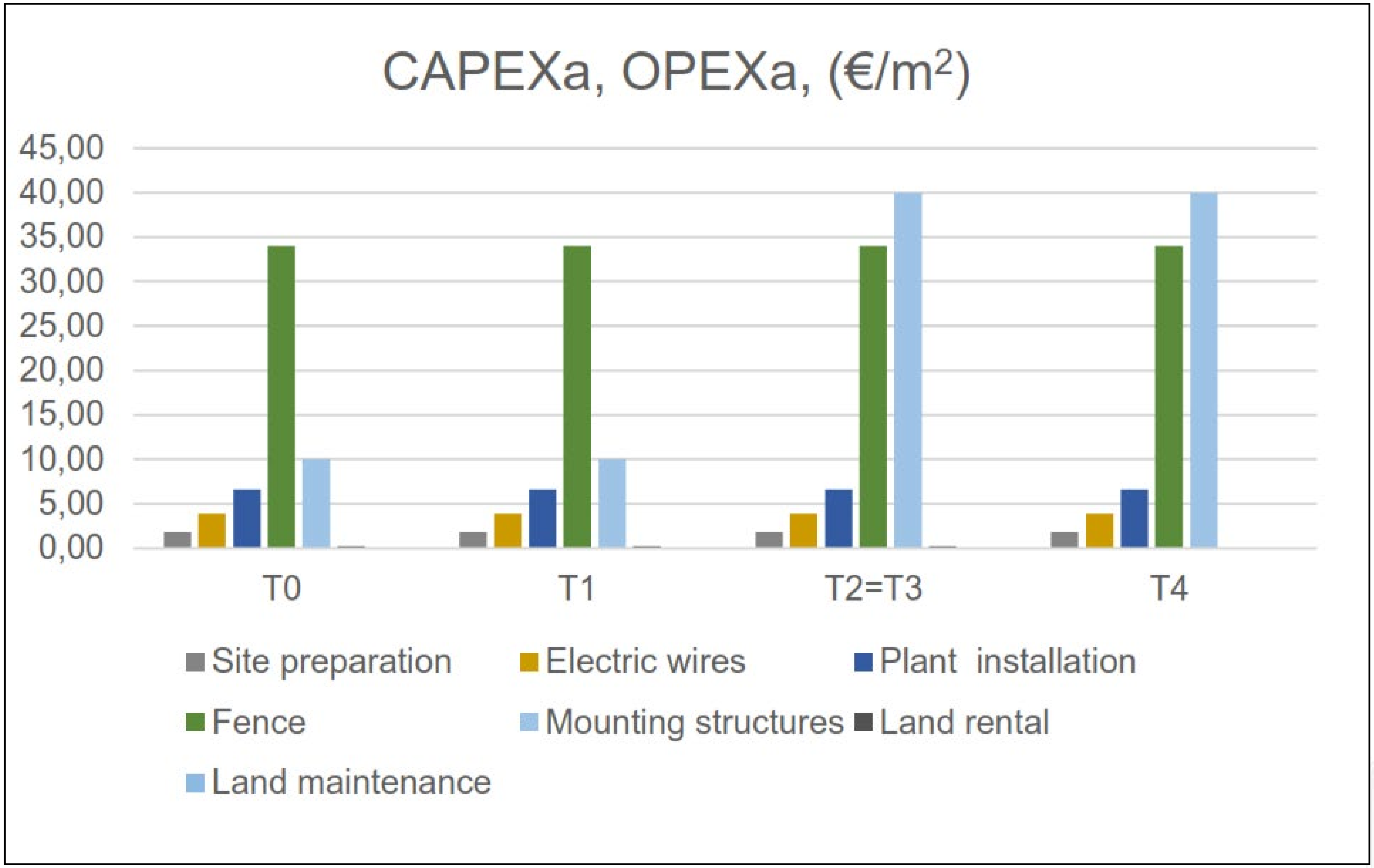
Agrivoltaic: costs

Capacity dependent CAPEX and OPEX costs of the photovoltaic systems, in EUR/kWp



Agrivoltaic: costs

<u>Area</u> dependent CAPEX and OPEX costs of the photovoltaic systems, in EUR/m2



Agrivoltaic Costs: Results

Levelized cost of photovoltaic electricity in €/kWh, for the different types of plants here investigated.

		AGRIVOLTAIC		
1 MW PV plant	T0	T1	T2=T3	T4
LCOE, EUR/kWh	0.069	0.073	0.095	0.092
			INNOVATIVE	

Cost + 30%

Photovoltaic revenues

How much money can I get from a 1 MW plant in Italy?

Assuming a market price of 13 c€/kWh:

1) **T0→75000€/ha**
2) **T4→44000 €/ha**

Farming revenues

Region	Durum Wheat (EUR /ha)	Common Wheat (EUR /ha)	Corn (EUR /ha)	Sunflower (EUR /ha)	Soybean (EUR /ha)	Potato (EUR /ha)
Piemonte	1531.16	963.96	2300.08	671.12	980.21	14,427.52
Valle D'Aosta						4453.85
Lombardia	1723.14	1089.57	2362.22	828.56	1198.66	13,214.29
Liguria		490.68	904.76			8494.41
Trentino Alto Adige		757.28	906.25			13.865,51
Veneto	2118.81	1207.84	2129.48	762.87	1099.18	25,068.38
Friuli Venezia Giulia	5022.47	765.95	2276.58	811.82	1011.17	17,920.63
Emilia Romagna	2118.25	1196.76	1902.97	678.79	1352.20	21,004.38
Toscana	1362.31	715.03	1574.61	527.71	679.86	9861.41
Umbria	1622.47	904.38	1544.86	417.36	1500.00	6375.00
Marche	1576.10	907.36	1482.97	498.68	998.05	9306.57
Lazio	915.65	740.85	1876.14	433.86	625.00	14,826.93
Abruzzo	1405.05	746.72	1591.84	464.04	1022.73	18,206.03
Molise	1345.43	725.29	841.38	404.76		6576.19
Campania	1253.29	703.00	1408.02	544.91		28,188.95
Puglia	976.99	506.33	1136.90	430.61		31,650.94
Basilicata	1080.37	509.93	883.07	469.39		9285.71
Calabria	975.95	565.61	836.10	500.00	750.00	14,755.99
Sicilia	988.57	512.82	1240.00			53,961.69
Sardegna	917.52	399.25	1761.30			62,837.94

Annual Values of the Agricultural Production for several extensive crops at the regional level in Italy (Elaborations by Crea on Istat data).

The italian average agricultural revenue per ha is less than 5000 EUR.

Agrivoltaic revenues vs farming revenues

Agricultural revenues are much lower than electric energy revenues.

Even if the UE support to the agricultural sector, the Common Agricultural Policy, CAP are considered, they are generally **less than 3000 €/ha** and therefore they cannot change the situation:

Agrivoltaic revenues vs farming revenues

According to: Nakata, H.; Ogata, S. Integrating Agrivoltaic Systems into Local Industries: A Case Study and Economic Analysis of Rural Japan. Agronomy 2023, 13, 513. https://doi.org/10.3390/agronomy13020513

1) Agrivoltaic results in an imbalance between agriculture and energy production due to the different revenues;

So that "There is a increased risk that agricultural lands can be abandoned"

2) a lack of safety,
3) non-contribution to the local economy.

Agrivoltaic: c) risks (known)

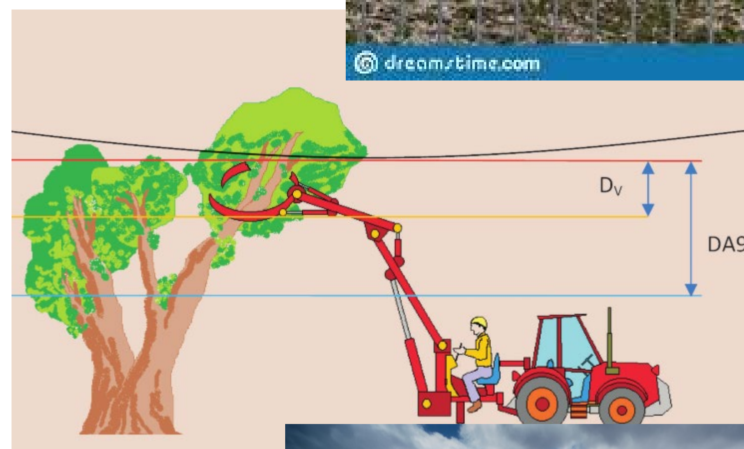
	Phenomenon	LCOE effect
1	Increased tendency of photovoltaic modules to get dirty	+n*0.6 c€/kWh, n= number of cleaning cycles;
2	Reduction of impinging solar energy due to dust from agricultural activity	In Italy a 0.3%/ppm decrease in solar irradiance has been calculated as a result of environment pollution. No data yet exist for cropland activities.
3	Increased cost of assembly structure	+n*1 c€/kWh, n= doubling the base installation cost;

Agrivoltaic c) risks (less known)

	Phenomenon	LCOE effect
4	The cleaning of the system must be done taking into account farming.	Unknown
5	Potentially harmful cleaning products cannot be used in a land used for farming.	Unknown
6	The compatibility of pesticides used in agricultural practice must be evaluated	Unknown
7	Worsening crop growth control	Unknown

Agrivoltaic c) risks (less known)

	Phenomenon	LCOE effect
8	Safety issue for farmers.	Unknown
9	Compliance with safety standards	Unknown
10	Crop shading	Unknown
11	Soil evaporation mitigation	Unknown
12	Inhomogeneity in the distribution of rainfall	Unknown
13	Increase in total area for cropland operation	Unknown



Conclusions

1) PV: is there a problem of land availability?	N
2) Is agrivoltaic technically possible? (question a)	Y
3) Are agrivoltaic costs sustainable? (question b)	Y/N
4) Are agrivoltaic systems well known? (question c)	N

Thanks

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