ISSN 2976 - 730X
IPI Letters 2025,Vol 3 (4):O44-O73
https://doi.org/10.59973/ipil.270

Received: 2025-09-18
Accepted: 2025-09-23
Published: 2025-10-06

Opinion

Solar Hydroelectric Energy: a Challenge for Sustainability and AI/IT-Energy Needs

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Abstract - After explaining the reasons why energy is one of the challenges for the future, regardless of human choices in many other fields, the author emphasizes how the entire EU, including Italy, remains highly dependent on energy. Without being able to reject other conventional sources in times of crisis, under penalty of regression and decline, the need to exploit solar energy is thus imperative, despite the volatility of photovoltaic or wind generation and the resulting risks and constraints to which a highly interconnected electricity grid exposes. This is also reflected in the risks of an isolated or poorly interconnected grid, which requires regulation in the context of the expansion of renewables. The author suggests the reasons for moving toward "hydro-solar projects" (hydroelectric pumping units powered by large photovoltaic plants), reclaiming areas of compromised, sometimes polluted, or decommissioned land, and in any case not intended for agricultural use. In this context, EU ETSs are therefore seen as a tool that can help pay for these new plants, which exploit renewable energy and constitute remediation measures, as well as potential energy storage and regulation infrastructures serving the energy needs of local communities, also promoting their development. Preliminary and exploratory considerations have led to initial technical, economic, and financial simulations, reported here in tabular and graphical form, which demonstrate the limits of feasibility/bankability in the current context based on expected production costs and grid placement prices; prices still significantly higher than those of the European market in general. The question therefore arises as to whether land and environmental care and remediation measures, such as the proposed infrastructure measures (electricity grids and new plants to replace old and polluting ones), which have impact on human health, the planet, and its obsolete infrastructure, should be subject to market rules. In this regard, further reflection is needed, also in view of the more demanding energy requirements for the spread of AI/IT and the necessary data centers.

Keywords - Sustainability; Renewable energy; Photovoltaics; Hydro-solar projects; Grid interconnection; Energy independence; Primary regulation; ETS; ESG; Challenges; Climate change; Environmental impact: AI/IT Energy Needs; Data Centers.

1 Introduction

Among the greatest challenges facing humanity is sustainability, in generalised mode, in every field of activity. Today, decision science and management are shifting toward new rather than traditional approaches, thanks in part to AI and multidimensional data analysis that enable more measured and rational choices. For example, for projects, alongside System Value Management (SVM) rather than traditional Total Cost Management (TCM), ESG (Environmental, Social, and Governance) criteria are becoming increasingly popular. These provide a relevant framework for reconfiguring traditional management practices within a sustainability-focused paradigm, emphasizing the interconnections between sustainability and organizational performance in every production facility of goods or services. Therefore, you don't have to be a prophet to have a possible vision of the future, especially since the increasing energy demand for the expansion of artificial intelligence and IT (typically: data centers) requires ever more energy. Whatever the scenario (economic-demographic growth or decline, population or radical depopulation, war or peace, cooperation or competition, national sovereignty or cosmopolitanism, etc.) and whatever path human civilization takes in the future, we can firmly believe that the challenge will always be energy and environmental protection. The ESG approach, like any other, is a paradigm that does not determine, but presupposes, energy, without which human civilization falls into impotence and regresses. Even the WEB, AI/IT, and BLOCKCHAIN (including HFT-High Frequency Trading upon which modern finance is built) are powerless if there isn't sufficient energy available. Furthermore, not only an Italian issue but also a broader European one, it involves the interconnection of grids and the primary control of frequency and voltage of interconnected grids for electricity transmission and distribution. «The European electricity system is interconnected: a problem with energy exchanges in the Balkans has repercussions across the entire continent. . . . .. The electricity system in the coming decades faces numerous challenges in maintaining stable frequency, and with it the reliability of supply, through reliable and affordable resources (RSE, Dossier 01/2017) [1]. It cannot be ignored, however, that one of the advantages offered by grid interconnection and the free, but controlled, electricity market is the injection into the grid of quantities of energy produced (e.g. during the day, when photovoltaic systems are active) that can be taken from the grid when needed (e.g. during the night, for hydro-pumping needs), making them the subject of appropriate agreements, compensation and adjustments bylaw.

Electricity production from wind and photovoltaic power is known to exhibit significant variations throughout the year, month, day, and even within a single hour. The variability of wind and photovoltaic power, as well as their respective capacity factors, which are much lower than those of other generation technologies, are well known and summarized in the following figure.

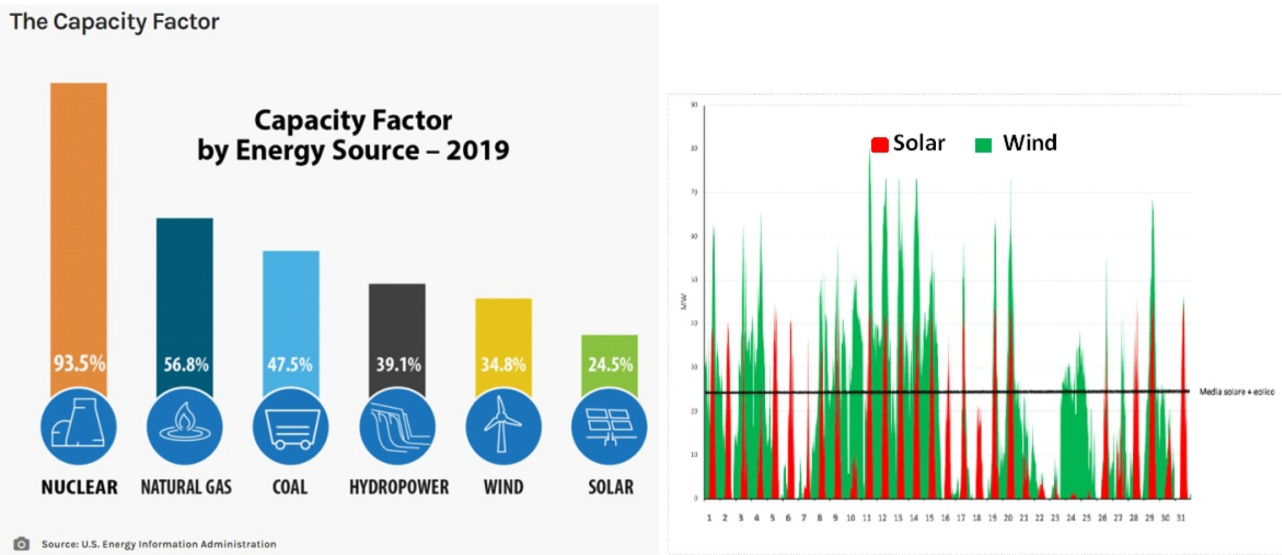


Figure 1: Variability and intermittency of wind and photovoltaic (Sources: US EIA + https://www.rivistaenergia.it/2021/04/variabilita-e-intermittenza-di-eolico-e-fotovoltaico/)

It is an established fact, and must be taken into account in planning, that two 50 MW plants with overlapping production, one wind and the other photovoltaic, together produce as much as an ideal plant of another type that operates at a power of~ 25 MW continuously (see Energy Magazine 2021 04) [2]. Therefore, 1 GW of nuclear or thermoelectric power does not correspond to 1 GW of photovoltaic or wind power in terms of producibility.

Ultimately, due to their intrinsic variability and modest capacity factor, it is practically impossible to expand the wind and photovoltaic power of an electricity system beyond certain limits without providing adequate "rotating" power (peak-load hydroelectric, as well as base-load nuclear and thermoelectric) that can ensure voltage and frequency regulation, as required by electricity service continuity and safety criteria. Although this was clearly demonstrated in the recent blackouts in the Iberian Peninsula, some planners appear to be able to ignore it, perhaps driven by the alternative of battery storage systems, which currently appear unviable, not only for environmental protection reasons. Such an option should be evaluated and discussed in a separate, multidisciplinary study. It should also be remembered that Europe, both a promoter and a victim of industrialization, is dotted with abandoned industrial sites, sometimes polluted and polluting (for example, nuclear, petrochemical, mining, chemical-pharmaceutical, chemical-biological, municipal waste landfills, etc.), which must be remediated and returned to their original intended use. Where possible, prioritizing the reuse of such sites to accommodate large-scale photovoltaic systems would not only enable productive reuse for the necessary energy, particularly nearby data centers, but would also facilitate efforts to remediate and reuse them without consuming additional land for new plants or installations. If those lands were usefully suitable for agriculture or pasture, they would play a primary role in agro-food sustainability and should be made unavailable for any other use. It should also be emphasized, as the recent speculations on energy market have been confirming for some time, that for the common good, there is a great need to increase each country's energy independence. And—given that sunlight is still available and free everywhere—the use of photovoltaic energy appears to be becoming one of the most cost-effective ways to do so. For over two decades, Italy, like other EU countries, has imported photovoltaic panels worth tens of billions of euros, with the investment's impact primarily abroad. ENEL's initiative to create a national supply line in Sicily (as Germany has long done) could make a difference, especially because it focuses on bifacial panels, which promise a 10 to 25% increase in output compared to traditional panels and offer a price point similar to the latter. At our latitudes (e.g., Rome), with optimal exposure, annual production is around 1100-1300 kWh/kW installed (see Fig. 20 in the Appendix). In the Sicilian plants planned by ENEL, production levels of nearly 2000 kWh/kW installed are expected. Typically, 1 kW peak (kWp) is achieved with~ 10 m^2 of panels. For the areas required for photovoltaic fields,~ 1.5 ha/MW are estimated, also for operation and maintenance reasons. Furthermore, it is noted that photovoltaics integrate well with pumped hydroelectric plants, because pumping can take place at the expense of the solar energy produced by the photovoltaic system (refer to Fig. 7.A and 7.B below). However, photovoltaics is not only functional for cost-effectiveness and pumping, but also for that of data centers, for example, which are expected to expand substantially due to the spread of AI. Furthermore, combined with pumping, which in itself is already an energy storage system, the installed hydro-photovoltaic system can constitute a real energy reserve for local needs, in times of crisis, ensuring energy security and a water reserve function through hydro-solar systems of reasonable power.

The direct link between sustainable energy and environmental protection is undeniable as much as we think about the growing energy needs to spread artificial intelligence and information technologies. This connection also extends to the climate change emergency. Potential hydro-solar projects are installations that foster the expansion of renewable sources, solving the problems of primary frequency and voltage regulation that prevent their widespread adoption as a replacement for other fossil-fuel or nuclear-powered sources. They would help mitigate the effects of climate change and safeguard the environment through lower emissions. Through EU-ETS (Emission Trading System)[3], they would also serve as a tool for financing their construction, making ETS no longer a mere tool for keeping old, polluting plants running simply by holding emission certificates. Given the venue for this discussion, a closer look at the proposed topics seems appropriate. Rather than providing certainties, it seems appropriate to raise questions and provide data and examples to encourage further investigation. All this is to open up spaces for thorough, institutional, and authoritative investigations that shed light on some of the general issues that appear to be taking on controversial aspects, such as the anthropogenic origin of on-going climate change. At least according to the perception of many in the general public, but also of some individuals or groups in the scientific community, climate change may not have anthropogenic origins. A prime example of literature on this subject[4] is "Dialogues on Climate," edited by A. Prestininzi with the scientific contribution of CERI – Digital Edition 2022 – Rubettino

Editore. This and similar collections of articles and research by various academics in various fields lead to questions about many topics regarding the energy transition and the anthropogenic causes that make it necessary. The emerging questions may concern, depending on individual sensitivity and knowledge, the following:

- a) the true weight of CO_2 as a scientifically recognized driving force of the greenhouse effect in climate change, given, for example, that in comparative terms, water vapor could have a determining and prevailing effect, also given the small amount of CO_2 in the atmosphere compared to water vapor and other constituents;
- b) astrophysical causes: effects or contributions, for example, of solar cycles, coronal mass ejections, meteor bombardment of the planet, changes in the effectiveness of the planet's natural electromagnetic shields, energy density of galactic and extragalactic cosmic radiation, and gamma ray blasts, etc.; all processes that bring energy to Earth;
- c) geological causes: for example, internal heat and radioactivity, rising plumes, energy released by seismic and volcanic effects, etc.;
- d) the impact of anthropogenic causes on the observed climate change, given that they are accompanied by causes or contributory factors of various origins:

- Demographic: since the human body is a source of heat, on average, of~ 80 W from metabolic processes;
- Intensive livestock farming: the above effect also exists for mammals raised for food;
- Plant-based: Trees dissipate metabolic heat primarily through transpiration (water absorbed from the soil and water vapor released from the leaves, which cools the tree) and convection (heat exchange with the surrounding air). Additional strategies include orienting cooler leaves upward for photosynthesis and using soil moisture;
- Energetic: Increasing dissipation of energy consumed on the Earth's surface (for industrial, transportation, domestic, etc.) could lead to negligible accumulations in the short term, but significant in the long term, as these are additive effects whose dissipation into deep space necessarily requires an increase in temperature, at least locally.

The current scientific consensus seems to focus on fixed points, some of which are briefly summarized here below.
Climate models include: solar variability, volcanoes, anthropogenic greenhouse gases, aerosols, carbon cycles, water vapor feedbacks, clouds, vegetation, and land use. They, however, treat as negligible: geothermal heat, seismicity, human and animal body heat, and direct energy dissipation. They do not include (except in extreme or paleo-climatic scenarios): meteorites, gamma-ray bursts, and significant changes in the geomagnetic field (because their energetic effects are considered minimal).

The relevance of water vapor, then, is based on the impossibility of divergent effects. Water vapor is a more powerful and abundant greenhouse gas than CO_2, but its atmospheric concentration is believed to be stable over time, making it a feedback (an amplifier) rather than the primary driver of current global warming, which is instead attributed to the increase in CO_2 and other anthropogenic greenhouse gases. But since it is a feedback, one might ask what the limit to the increase in water vapor is that makes the greenhouse effect a potentially unstoppable divergent process. The answers lie in the fact that the climate system is not an "open loop", but also has negative feedbacks and physical limits: clouds, which can in-crease reflectivity (albedo); thermal radiation emitted by the Earth, which increases with temperature (the Stefan-Boltzmann law); and atmospheric and oceanic processes that distribute heat and humidity. Therefore, water vapor is considered amplifier, but by itself cannot make the climate indefinitely unstable.

Water vapor as a feedback has a limit: it becomes divergent only if the Earth's capacity to radiate solar heat into space is exceeded: that is, the "uncontrolled greenhouse effect." Physical estimates show that

this limit is unattainable with current CO_2 emissions: it would require warming of tens of degrees, far beyond current projections. Therefore, the increase in vapor amplifies the warming, but does not make the Earth's climate catastrophically unstable. Climatological studies (Kasting, Goldblatt, and others; see references in Appendix 2) estimate that on Earth the radiation limit corresponds to an average global warming of about +70^{0}C compared to today; that is, when the atmosphere would be almost saturated with water vapor. Current anthropogenic warming of a few degrees ^{0}C does not even begin to approach that regime.
In Fig.2, is a conceptual graph of the radiation limit (Simpson–Nakajima): it shows how the OLR (Outgoing Longwave-infrared Radiation) increases with dry temperatures but, in the presence of large amounts of water vapor, tends to an asymptote around~ 300 W/m^2. As long as the maximum OLR remains above the absorbed solar energy ($\tilde{2}$40 W/m^2), the system finds equilibrium: there is no divergence. The runaway greenhouse would only begin if the absorbed energy consistently exceeded that limit, which is far from the case today. A separate and more extensive literature search on these widely studied topics, conducted using Deep Search, is included in the Appendix for further reading.

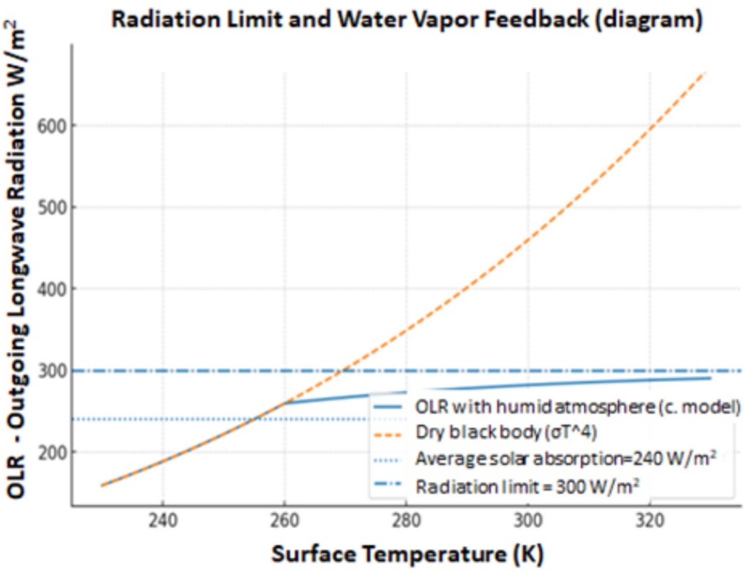


Figure 2

Regarding the climatic significance of the various sources known today, it should be noted that, in summary, only the sun and greenhouse gases are considered strong drivers of global climate. Solar variability and volcanoes have measurable effects, but they are considered minor and temporary. All other direct energy contributions (human heat, animals, geothermal energy, meteorites) are orders of magnitude smaller and do not seem to impact the global climate balance (see Table 1). It should be noted, however, that according to the following table, anthropogenic waste heat (20 TW globally), although small globally, can be significant locally (e.g. causing urban heat islands), especially in large cities or large industrial clusters. Considering that the variation in the energy flux induced by anthropogenic greenhouse gases (=2.7 W/m^2), considered that the current effective net forcing is about 1% compared to the solar flux ($\tilde{2}$40 W/m^2), this means that multiple non-anthropogenic effects combined with particular local situations in a given place can produce adverse effects in the so-called "microclimate" (e.g. areas adjacent to closed seas that tend to heat up in the warm season beyond the usual average temperatures and producing unusual levels of air humidity. And the so-called comfort curve, which measures the perception of heat, well known in thermo-technics, is a function of both temperature and humidity!).

Source	Energy Flux (W/m²)	Climate Relevance
Sun (average absorbed energy)	~ 240	Critical, main driver
Solar variability (11-year cycle)	~ 1	Small but included in models
Anthropogenic greenhouse gases (current net forcing)	~ 2.7	Very relevant, cause of current warming
Internal geothermal heat	~ 0.09	Negligible at the climate scale
Volcanic eruptions (stratospheric aerosols)	≈ –0.1(episodic cooling)	Episodically important, included in models
Anthropogenic waste heat (20 TW global)	~ 0.04	Small globally, important locally (urban heat islands)
Human metabolic heat	~ 0.0005	Negligible
Animal husbandry (animal metabolism)	~ 0.001	Negligible (significant effect only via CH_4 and N_2O (already included)
Meteorites (average energy flux)	~10^{-6}	Negligible

Table 1: Climatic Relevance of Different Sources. (Source ChatGPT).

Climate change also inevitably impacts human health through increased heat-waves that cause cardiovascular and respiratory diseases, the spread of infectious diseases transmitted by mosquitoes and ticks, worsening air quality resulting in respiratory diseases, food and water shortages leading to malnutrition, and a negative impact on mental health due to extreme weather events and stress. Concern about CO_2 levels has long been a driving force, resulting in some issues being overlooked rather than highlighted. Examples include the absorption of micro-plastics, whose effects on human and environmental health are gradually emerging, but even fine particles sometimes seem forgotten, despite the proven harm they cause to human health.

Year	Energy (Power Stations)	Transportation (total)	Domestic Heating	Other sectors
2010	1.8	44.7	121.8	38.3
2015	0.8	30.0	105.6	29.0
2019	0.5	25.1	92.8	28.5
2022	0.5	22.7	92.0	28.9

Table 2: $Pm^2.5$ emissions (kt/year) by sector in some key years (Italy). (Source: ISPRA National Inventory).

The table above shows that from 2010 to 2019, there was a clear improvement in $Pm^2.5$ particulate matter in Italy, but since then there have been no significant reductions, and one gets the impression that a limit has been reached that can no longer be improved. One almost gets the feeling that a limit is insurmountable.

The sense of an insurmountable limit is even more evident when looking at the total $Pm^2.5$ data for the entire EU (see Tab. 3), especially in graphical form, where the magnitude of the trend overall and across different sectors can be immediately seen in the following graph (see Fig.3 below). There have been fairly limited improvements up to 2018, but since 2020, it's difficult to say whether the observed stagnation has occurred due to intrinsic technical limitations or the ineffectiveness of the policies adopted.

These above reported are traditionally explanatory arguments for climate change and the need for an energy transition. Although they do not directly question past or on-going modeling due to their scope and the results achieved to date, do not always seem to elicit absolute and widespread consensus among the various scientific communities, especially those most critical and distant from the mainstream consensus.

Year	Total EU-27	Electricity Production (Power industry)	Transport (Road + Non-road/Shipping/Aviation/Rail)	Domestic Uses (Energy for buildings: Commercial/Institutional/Households)	Other uses (industry, processes, agriculture, waste, etc.)
2018	1 250	39	144	808	260
2019	1 200	37	138	775	250
2020	1 120	35	129	723	233
2021	1 180	37	136	762	245
2022	1 100	34	127	711	229

Table 3: EU-27 – $Pm^2.5$ by sector (kt/anno) – Source: EEA (European Environment Agency).

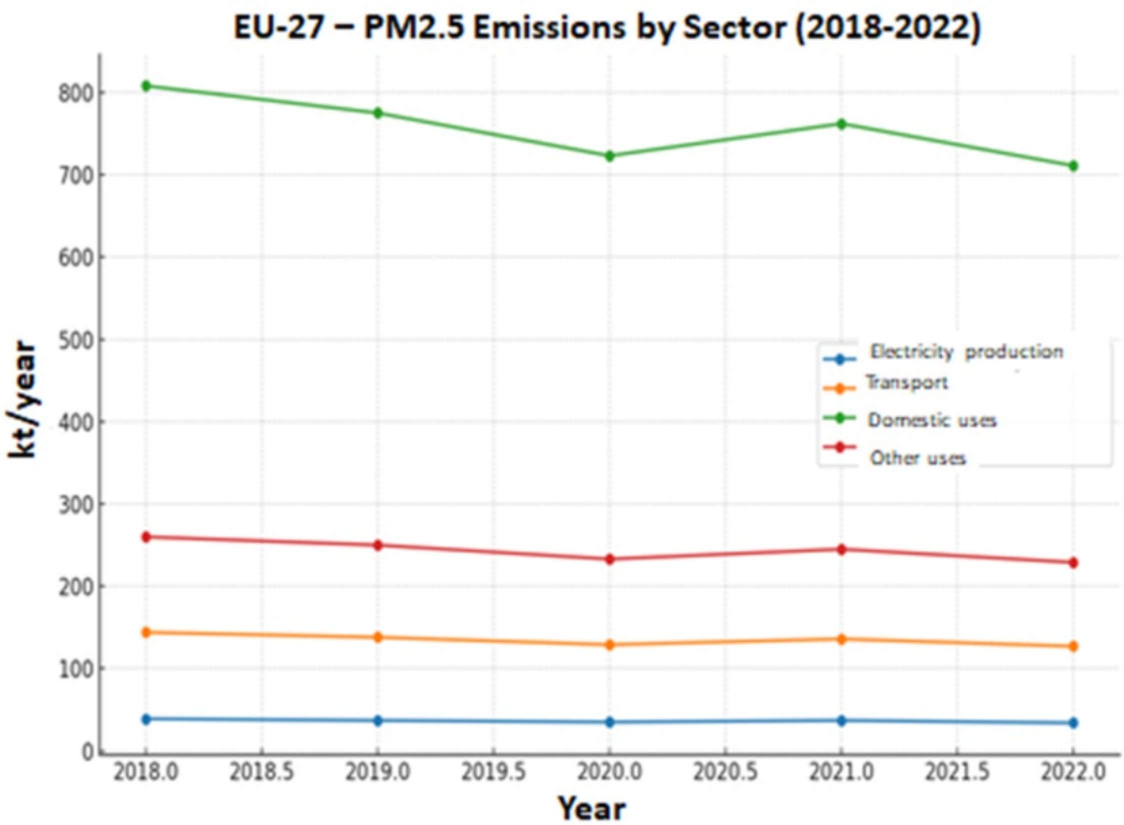


Figure 3: Recent $Pm^2.5$ Emissions Trend in EU-27 (Source: Deep Search)

Adopting the precautionary principle in emergency protection policies is appropriate if combined with a balanced scientific consensus and the duty to investigate the underlying causes, without forcing one direction or another, but responding and acting with rational explanations to the arguments of those scientific communities, albeit a minority, who struggle to reach consensus on the controversial aspects they highlight in dialogue. Controversy filled with arguments that are sometimes overlooked and not always lacking in coherence or foundation. Dissent is, however, part of a democratic civilization. And while mainstream scientific consensus can carry great weight, scientific truth comes to us from experimental verification, rather than from majority consensus. Therefore, it is on these "experiments" that we must shift the discussion, identify any necessary policies, and gain consensus through them. Without forgetting that dissent, however minority, can have a critical power of "triggering" counter-information toward positions perceived as "pre-established" by general public opinions. Perhaps, for this reason, it has not helped to ignore the logistical, infrastructural, and above all human and environmental damage caused by sinking Nord Stream, as well as that caused by on-going wars, or worse, the nuclear wars they could unleash. The perceived lack of integrity in the balancing of an information system does not foster the climate of trust necessary for consensus, which is needed to implement remedial plans for the emergency situations into which we have been plunged, certainly not suddenly, nor unknowingly.

2 Discussion

2.1 EU (and Italy) are net importers of energy (and not just electricity)

The European Union is a net energy importer, meaning it imports more energy than it exports. In 2020, over half of the EU's energy came from imports. In particular, the EU is heavily dependent on fossil fuel imports, with Russia as the main supplier. In 2020, approximately 58% of the EU's energy was produced outside its borders. Italy's dependence on foreign sources of supply is an established fact, and even more critical. Approximately 7% to 15% of electricity is imported even from nuclear sources. In 2022, fossil fuel imports covered 78% of Italy's energy needs. In 2024, Italy saw its energy dependence on foreign sources decline, falling to 72%, thanks to lower fossil fuel imports and an increase in domestic renewable energy(mainly PV and Wind). Despite this, Italy continues to have a high need for imported energy, and although energy expenditure has decreased significantly compared to 2022, it remains one of the European countries with the highest dependence on foreign energy. This makes it fragile and, in a free market context, some argue, exposes it to speculation, as necessary energy quotas can be granted at a higher price to ”wealthier” countries, resulting in de facto shortages and price increases on domestic markets. This raises energy security and sufficiency issues that imply geopolitical diversification of supply sources and diversification of production technologies, without exception, nuclear first and foremost.

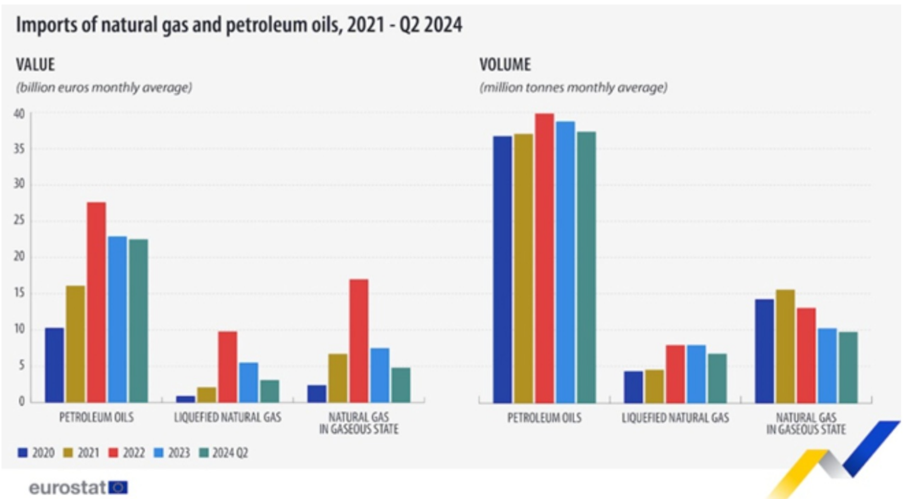


Figure 4: Fossil fuel imports into the EU in the last five years.

But how sustainable, in general, is the use of thermoelectric power and therefore fossil fuels, even low-carbon ones (i.e., gas), through the holding of green certificates to cover the resulting emissions, when there are~ 2,000 GWe installed globally, with an average lifespan of~ 15 years (for coal alone)? This is one of the first real challenges, since emissions caused by fossil fuels – particularly fine particles Pm^{2}.5, PM10, as well as CO_2 and other greenhouse gases – can contribute to adverse effects on human health and ecosystems in general. On the other hand, humanity is not in a position to give up any of the energy sources known today until it has new, clean sources and technologies that meet the concept of ”proven technology” (i.e., continuous operation for 8,000 hours/year).

This clearly implies the need to promote energy research well beyond market conditions since it is the states themselves that are called upon to take action to safeguard the communities they manage and for whose future they are responsible. If all this is lost sight of, it becomes inevitable that popular thought (often labeled “populist”) will spread and call into question the very basis of the legitimacy of the power to which it is subjected.

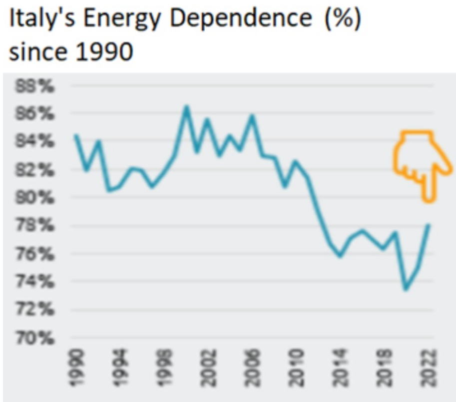


Figure 5: Energy Dependence in Italy.

2.2 Stability of National and Local Electricity Grids

To give an example, Sicily case will be discussed here, but the discussion can be extended to any region, not necessarily geographically isolated, but isolated in terms of grid interconnection. Given the potential offshore wind projects in Sicily totaling approximately 3 GW—plus a further 4 GW planned for photovoltaic installations, on an overall existing local power of approximately 9.5 GW—one must ask whether, with the continued expansion of photovoltaic and wind plants, the electricity grid to which they connect can remain stable. There are reports and evident occurrences that other European countries, accelerating renewables, have experienced instability problems. Partly because, typically, frequency and power regulation, in the past, occurred at the national dispatching level, at High Voltage (HV). Today, however, an increasing number of wind and photovoltaic plants are being connected to Medium or Low Voltage (MV/LV) grids. And not everyone is convinced that the regulation applied to the HV grid is immediately effective on local MV/LV grids, wherever they are located. Are they wrong? It doesn't seem so, because between the HV transmission grids and the MV/LV distribution grids there may be transformation and power factor correction substations.

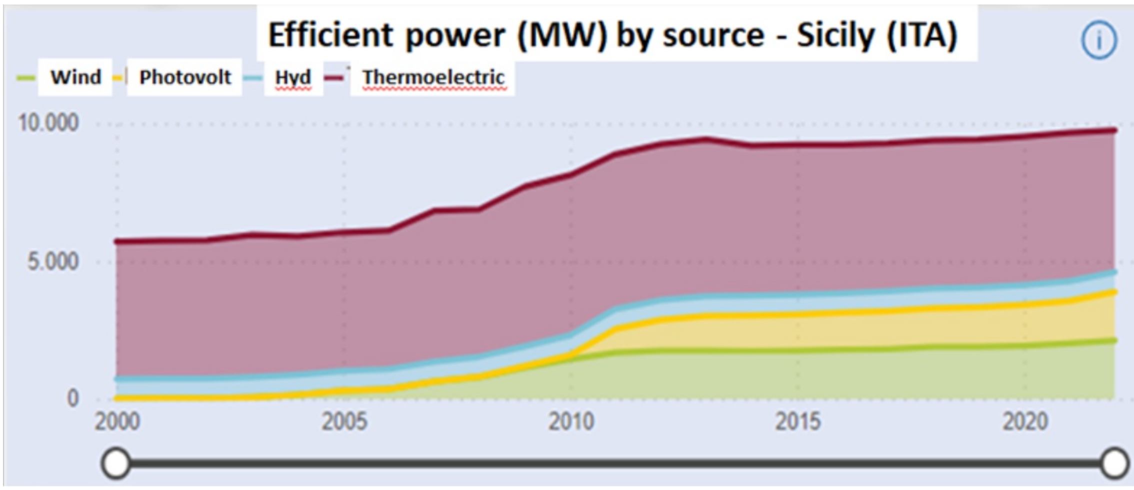


Figure 6: (Source: TERNA)

2.3 Compatibility between sustainability and growth in the context of ongoing climate change

Regardless of the controversies between proponents of anthropogenic causes and those of natural cyclical causes, climate change appears to be incontrovertibly demonstrated in the measurements and monitoring of objective geophysical parameters, as well as in the concrete environmental effects that modern science and technology make available through continuous monitoring. The range of possible causes (anthropogenic, cyclical, geological, astrophysical, etc.) seems to push legislators—beyond cause-and-effect research—to take into account a "precautionary principle." This is also under pressure from more or less targeted information and media campaigns that amplify the resonance of a "catastrophism" not shared by all, due to the imperative adoption of energy models aimed at decarbonizing economies. Although to date, there has been a shift in the taxonomy regarding nuclear power at EU level, this occurred precisely when some economies were rejecting nuclear power (German model) and others were adopting it to support their green policies (Swedish model). In fact, leading research scientists (e.g., MIT) have consistently warned of the impossibility of a global energy transition without nuclear power, and the EU itself advocated (in its original Energy Road Map 2050) a 20-30% nuclear mix in its member countries, although countries like Italy had decided otherwise (e.g., importing this share). As the study of on-going changes continues and becomes more refined, the spectrum of possible causes considered will inevitably broaden; causes that sometimes remain to be fully explored. Furthermore, although the effects on the natural environment are also widely studied, the socioeconomic and geopolitical impacts appear to be underestimated, with the exception of the formulation by certain schools of thought (see "Decoupling/debunked" a 2019 Report of the European Environmental Bureau-EEB -) [5] about an inevitable policy of "de-growth", which is sometimes manipulatively associated—especially in Italy—with the attribute of "happy." The incompatibility between sustainability and development is still taken for granted (and not only by EEB), even in a context of green growth. The first socioeconomic and geopolitical studies on the effects of de-growth (which, for other reasons, has already been emerging in Italy for some time) are tentatively being explored. Reflections on these issues seem to point with concern to potential de-growth policies and the monoculture of "green and low-carbon" gas energy, the risk of unsustainable public debt and jeopardizing political, social, and financial stability, as well as the elusive global peace. This is precisely as a renewed nuclear armament and conflictual policies loom on the horizon, not only in the commercial sphere (e.g., tariff and currency wars) between major economies, but also between different "hegemonic" worldviews. Isn't this also what brought war back to Europe, regardless of its environmental impact, starting with the methane leaks from the sinking of the Nord Stream pipelines? So what kind of environmentalism are we even talking about in Europe?

2.4 Assuming that nuclear fusion becomes available

Until a few years ago, it was expected that the ITER project at the Cadarache site would be connected to the electricity grid in 2025. This is no longer the case. To be realistic in our predictions, let's hope that ITER, Divertor, Stellarator, and similar nuclear fusion projects will actually be available when our grandchildren need them! But the challenge with fusion isn't just achieving it in a stable and usable way for peaceful purposes. And looking at today's conflicts, doubts are already beginning to emerge regarding this latter aspect. Beyond this, there would also be the problem of entrusting an unlimited energy source to a society inspired by models of continuous growth, oriented toward ever-increasing production and consumption, and un-accepting restrictions, due to the resulting necessary limitations on balanced growth for global equilibrium and stability. Therefore, since thermodynamics doesn't lie, the Earth's atmosphere would, above all, remain an insulating blanket in a terrestrial system that would likely receive an increasing amount of heat from the widespread use of fusion energy, especially due to the growing consumption produced by AI, BLOCKCHAIN, IT needs, where there is already talk of a "Information Catastrophe"(see M.Vopson 2020)[6]. A term that refers to the difficult energy sustainability to fuel the current trend of growing information production. Therefore, the temperature would rise. Will this allow our planet's radiative equilibrium to be maintained when unlimited amounts of fusion energy are released above the Earth's crust, resulting in a rise in surface temperature? Or will climate change only then be recognized as being due to "genuine" rather than "uncertain" anthropogenic causes? Things are different in deep space (well beyond the thermosphere), which is a limitless cold well. From all this, it's a short step to considering development models with a steady-state economy and its associated limits. The question therefore arises whether a steady-state economy à la Herman E. Daly, or the Solow-Swan economic model, in which growth is achieved solely through innovation, can still be considered utopian while present reality continues to operate within the framework of open economies and the free market, a place where nature (natural resources) continues to become a commodity, increasingly expensive, polluted, and polluting, obtainable in exchange for a monetary equivalent, albeit a paper one, with no other real collateral value.

2.5 A possible turning point in the current picture

In accordance with EU and UN directives, for the de-carbonization of the economy and, in particular, for the creation of a more equitable and sustainable future, it seems appropriate to undertake pumping ”solar hydro projects” in our territory – see Figures 7A and 7B, which are intended to provide a conceptual example of a well-known possibility, but largely overlooked due to cost. And more than cost, it would appear to be avoided by profit lack, precisely when the Entrepreneurial State, which in theory seeks not profit but rather service to its community, is poorly tolerated and not permitted. An Entrepreneurial State not consented especially to some EU Member States, but permitted and admitted to other Member States based on their weight in the political arenas that matter, also due to their role in the attempt to politically unify the EU and its subsequent positioning on the global stage. However such a situation, dominated by a rigid free market, which flexes on command only, has proven to be short-termist. And those who have eyes to see, ears to hear, and a head to understand know that ”the short term has no future”; a truth inherent in its very semantics. Now more than ever, we need to rethink ”the” future: of businesses, families, young people, and society in general, in a context of bilateral/multilateral cooperation based on reciprocity, beyond geopolitics or autocratic, democratic, and theocratic political orientations. In ancient Roman civilization, land was the reward for soldiers returning from battlefields. But if a soldier is deprived of his land, can he still nourish his patriotism to the point of sacrificing his life? War for the domination of man over man no longer seems to be widely appreciated or accepted , precisely when a future of dignified survival could be assured for all today, if ideas of supremacy and domination were abandoned. If such a goal cannot be achieved, the least of the poor will no longer endure the discomfort of having not to attend a table set for the “privileged” only, without being able to partake themselves and satisfy their needs. In that case, they will come for their share, even by violence! And the blame will not be theirs alone, even if they are labeled “politically manipulated migrants” or even worse ”terrorists.” Continuing to rely on force and fear in governing peoples, invoking and misunderstanding Machiavelli (presuming in contradiction with the original text that for the Prince it is better to be hated than loved by his people), may be an unfortunate option. But initiating a choice through small, gradual, targeted decisions in selected territories still in need of water and energy can restore the trust shattered by years of reckless decisions and intentions. The bleak future that looms can be changed, and it must be done. This seems appropriate and necessary. And hydro-solar projects can be a first step in that direction, however small it may seem, like a sanctifying drop in the ocean of yet unsatisfied needs!

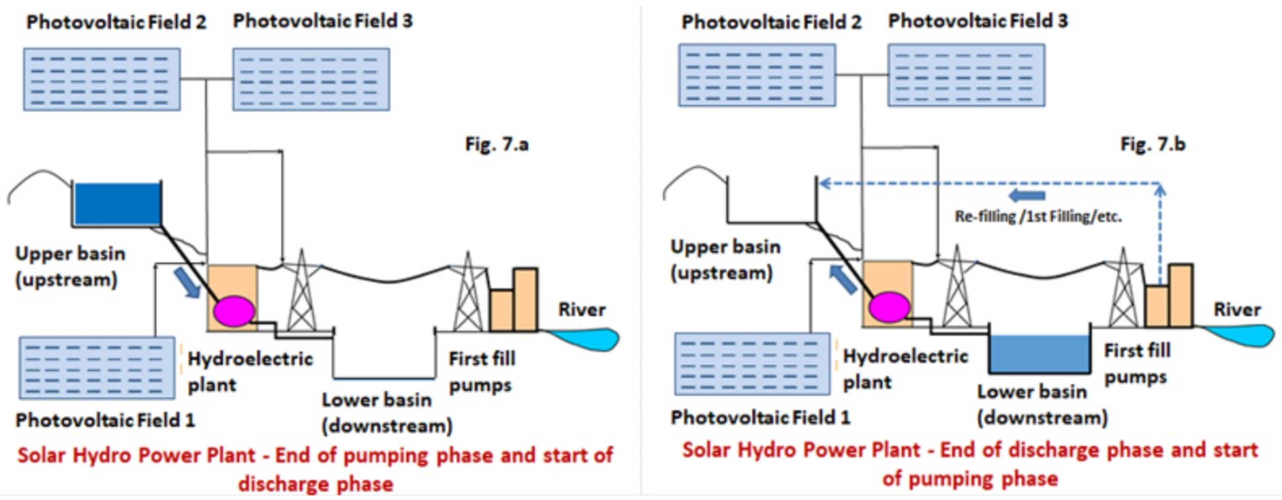


Figure 7: Two different phases of a Solar Hydropower Plant.

While it may appear like a droplet in the ocean of problems to be solved, integrating photovoltaic projects with pumped-storage hydroelectric projects, where the land allows, would signal change, widespread employment for businesses and workers, and the valorization of local areas and care for the population. It’s far from accelerated consumption of the last few remaining resources on this planet. These projects are necessary for electricity generation at the expense of solar energy, but above all, they are desirable for the stability and regulation of electricity grids in view of the future increase in industrial initiatives involving wind and photovoltaic plants, which provide ecologically clean electricity generation, but are electrically dirty because they are too variable and entirely "volatile." "Solar hydroelectric projects" not only provide pumped-storage hydroelectric energy through free solar energy. They are useful for the primary and secondary regulation of an electricity grid (stability of frequency and voltage as the power required varies), and they can also provide access to emissions trading on global stock exchanges through the creation of tradable green certificates for CO_2 emissions. According to the intentions of today's powerful figures, everyone will have to eliminate their own CO_2 footprint. Therefore, electricity generation using fossil fuels will in future be permitted only to those who hold an emissions certificate for the equivalent amount of carbon dioxide emitted. For example, that produced by burning fossil fuels used in conventional thermoelectric power plants that have not yet been shut down or decommissioned due to their polluting obsolescence. Furthermore, the proposed hydro-solar projects are initiatives that:

- i. They originate and develop locally, without giving rise to geopolitical dependencies.
- ii. They are anchored to the territory and can give rise to organizations (cooperatives, consortia, associations, etc.) for self-production and self-consumption, i.e., "energy communities and collective self-consumption."
- iii. They are labor-intensive and therefore create jobs by prioritizing industrial enterprise over finance.
- iv. They have a high impact on the local level.
- v. They integrate photovoltaic and hydroelectric power, meeting environmental sustainability criteria that underpin the energy transition with a view to decarbonizing economies. In fact, they do not operate through dams and diversions of a watercourse's basin, which create dead sections of the fluid veins used, nor do they require the relocation of entire villages or settlements, as has sometimes happened in large hydroelectric projects. (And this has created aversion to large-scale hydroelectric projects.)
- vi. They integrate photovoltaic and hydroelectric power, presenting themselves as a "peak service tool" suitable for filling power and energy gaps generated by contingent situations or even the lack of prior analysis of specific "energy insufficiency and insecurity," which have clearly exposed the energy poverty discussed in European forums.
- vii. They maximize the integration of photovoltaic and hydroelectric power when the photovoltaic energy produced is equal to or greater than that required for nighttime repumping, in the upstream basin, of the water turbined daily to ensure regular electricity service.
- viii. They change the very notion of a region's hydroelectric potential. Indeed, even in a region that lacks natural hydroelectric potential or has already exhausted it because it has already been exploited, as long as it still has a relief upstream and a river (or water) downstream, as well as sufficient surface area suitable for photovoltaic power, hydroelectric potential can be created "artificially" with a pumped-storage plant at the expense of solar energy. This is not rhetoric, but a concrete, feasible fact that is worth exploring and verifying for individual local initiatives.
- ix. They allow the generation of emissions trading revenues through the green certificate exchange, which constitute a significant portion of the investment cost, useful for repaying the project.

EU Directive 2018/2001, known as FER II, required member states to maximize the possibility of self-consumption of energy produced, even collectively, and to legally regulate Renewable Energy Communities. In light of a global and widespread commitment by all countries to combat and mitigate the negative effects of climate change, which has become increasingly evident and problematic for human activities, is a project with the requirements described above rejectable? Our "hydro-solar" project only needs "space," preferably hilly and south-facing, and not intended for other useful uses! There is plenty of land to be reclaimed everywhere, in Italy and Europe, as well as everywhere else; and the proposed plants may be located dispersed across the country, but they can all be used to serve a single project given the existence of one common interconnected electricity grid.

2.6 Some simulated examples

Six different plant options were simulated (at constant 2022 prices) and are reported in Summaries 1 and 2 below. They concern:

1. A hydroelectric plant with a hypothesized potential of 100 MW, equipped with a turbine-pump system, to provide primary and secondary regulation services for the local and regional electricity grid; this plant is viable and sustainable only if the pumping energy is provided at very low cost and without the use of fuel (that's why photovoltaics are used!);

2. A 300 MW photovoltaic plant, serving the pumping system to provide energy for cyclical pumping with a daily service of 7 hours a day; photovoltaic electricity is fed into the grid during the day (approximately 8÷12 hours) to be used for pumping at night;

3. A 400 MW photovoltaic system, serving the pumping station as an alternative to the previous one, also with the aim of making the local area self-sufficient in terms of its energy needs;

4. A 200 MW photovoltaic system, making the local area more than self-sufficient in terms of its energy needs, but not providing pumping and therefore regulation;

5. A 100 MW photovoltaic system, making the local area almost self-sufficient in terms of its energy needs, but not providing pumping and therefore regulation;

6. A 50 MW photovoltaic system, insufficient to make the local area self-sufficient in terms of its energy needs, but providing good local reserves.

Option 1 can obviously only exist in combination with 2 or 3. An economic analysis and a profitability simulation analysis were performed for each option. In the absence of a real engineering project, the results in Summaries 1 and 2 , and in the other tables as well, have only preliminary indicative value. To build 100 MW of hydroelectric power (with night pumping, 7-hour daytime service,~ 3 Mm3 of reservoir) at least 300 MW (better still 400 MW) of photovoltaic energy is needed on 450 hectares of land (equivalent to an area of 2.1x2.1 km). If, over its entire useful life, the market value of a ton of CO_2 avoided fluctuated between €30 and €60/ton of CO_2, as it did in 2021 (see Fig. 5), the 100 MW hydroelectric plant would generate green certificates over its life cycle with an average value exceeding €100 million, and the 300 MW photovoltaic plant would generate green certificates over its life cycle with an average value exceeding €200 million. The overnight cost, excluding financial charges, of the projects is[7-9]:
- to build 100 MW of pumped-storage hydroelectric power: €347 million (ref. EIA-US Energy Inf. Adm. estimate)
- to build 300 MW of photovoltaic power: €330 million (ref. our survey + EIA-US Energy Inf. Adm. estimate)

For further information, see Summaries 1 in Table 5 and Summary 2 in Table 6 below, the individual profitability graphs for the largest projects in Fig. 8 and Fig. 9, as well as the analysis of avoided CO_2 for ETS purposes in Fig. 9 and Table 7. The estimated costs for each type of plant were uniformly distributed over the respective timescales assumed in the programs illustrated below in Fig. 12 and Fig. 14 in order to calculate the indicators selected for evaluating the various project options. These indicators are the usual and well-known ones[10-16], namely:

- Net Present Value (NPV);
- Internal Rate of Return (IRR);
- Break-Even Time (BEP);
- Debt Service Coverage Ratio (DSCR).

This ratio, preferably of value 2, as a thumb-rule, should not fall below 1 in any financial year, and to ensure a certain margin, financiers believe it should be around a value at least higher than 1.5. The use of this index is due to the fact that profitability analysis alone is unable to assess every aspect of financing; this is because, at times, the IRR can remain at satisfactory levels even when the project's ability to repay the debt within a few years may be compromised [17-20].

The simulations were conducted both with grid prices for the kWh produced close to current Italian electricity market prices (see Summary 1)[21,22] and with grid prices higher than current market prices (see Summary 2). It can be seen that in both cases, when interest on capital is considered during construction period, there is a drop not only in the overall profitability of the investment, but especially in the DSCR value, as well as a lengthening of the break-even time. This means it is impossible to adequately (i.e., without risk) repay the investment. For example, Table 4 shows how the DSCR varies depending on the sector to which a project belongs. For projects in the Power Generation sector, bankability values of 2–2.5 are also required in cases where there are no offtakers (i.e., buyers) already committed to taking over the generation (e.g., a take-or-pay contract) or assuming ownership/management of the generation plant, e.g., in the case of BOT (Build Operate & Transfer) or BLT (Build Lease & Transfer) plants. The variability of DSCR values depending on the project's sector is summarized in Table 4 below:

Project Sector	Average DSCR
Wind farm	**1.30x÷1.50x**
Telecom	**1.35x÷1.50x**
Water with offtaker	**1.50x÷1.70x**
Power with no offtaker	**2.00x÷2.50x**

Table 4: DSCR by Sector Project Sector.

The table above serves as a reference for the simulations developed on the financing of various project options considered. Today, however, it almost seems as if the banking system is pursuing widespread indebtedness, but this debt cannot always be guaranteed and insured (preferably by governments) due to unavoidable risks and unforeseeable contingent situations. This may have hardly altered the percentage references before the subprime crisis due to "competition" between banks, but it could still cause downward pressure on the DSCR index. This is particularly true for large companies that are able to finance themselves on the capital markets by issuing their own securities, which can be purchased by the general public.

It's so evident that DSCR is not just a technical ratio but a risk management tool. In spite of competitive banking practices and capital market financing can weaken current discipline, creating systemic vulnerabilities, prudent lenders, regulators, and investors insist on sector-appropriate DSCR floors, even when headline profitability looks attractive.

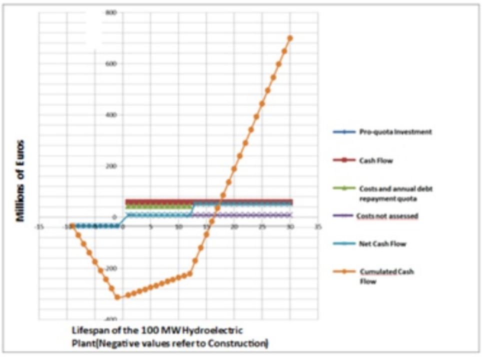
To reduce risks, this requires considering the issue of bankability not only at the end of a project's development, but rather from the early stages of exploring an industrial opportunity, for example in opportunity or scoping studies, refining the estimates as the project's development progresses.

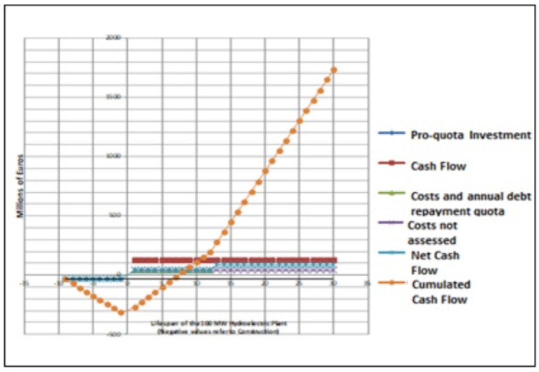
OPTIONS WITH GRID PLACEMENT PRICES PER kWh CLOSE TO THE CURRENT ITALIAN ELECTRICITY MARKET BUT DIFFICULT TO BANK - (Summary 1)							
SUMMARY OF THE DIFFERENT OPTIONS PRELIMINARILY CONSIDERED FOR A POSSIBLE HYDROSOLAR POWER PROJECT WHICH ARE DIFFICULT TO SUSTAIN UNDER CERTAIN TECHNICAL-ECONOMIC CONDITIONS EXPLICITLY STATED							
Item	Unit of measurement	Hydro 100 MW (1)	Photovolt. 300 MW (2)	Photovolt. 400 MW (3)	Photovolt. 100 MW (4)	Photovolt. 200 MW (5)	Photovolt. 50 MW (6)
Project Team,etc.	(mm. x years)	0	0	0	0	0	0
Peak Power	kW	100.000	300.000	400.000	100.000	200.000	50.000
Necessary Area	m^2	0	4.500.000	6.000.000	1.500.000	3.000.000	750.000
Annual Land Fee	€/m^2	0	0,25	0,25	0,25	0,25	0,25
Unit Cost of Plant Investment	€/kW	3470	1100	1100	1100	1100	1100
Plant Investment Cost	€	347.000.000	330.000.000	440.000.000	110.000.000	220.000.000	55.000.000
Interest rate	(r)	0,045	0,045	0,045	0,045	0,045	0,045
Loan Repayment Years	(n)	12	12	12	12	12	12
Annual Repayment Quota	(A)	38.054.167	36.189.842	48.253.123	12.063.281	24.126.562	6.031.640
Operation Hours 7x365		2555					
Annual productivity per kW	kWh/year kW	2555	1300	1300	1300	1300	1300
Annual Productivity	kWh	255.500.000	390.000.000	520.000.000	130.000.000	260.000.000	65.000.000
Annual O&M fixed costs	€/kW year	50	20	20	20	20	20
Variable Costs	€/kWh	0,002					
Tranche 1	kWh	1.500.000	1.500.000	1.500.000	1.500.000	1.500.000	1.500.000
Unit price Tranche 1 for grid placement up to 1,500,000 kWh	€/MWh	234	160	160	160	160	160
Tranche 2		254.000.000	388.500.000	518.500.000	128.500.000	258500000	63.500.000
Unit price Tranche 2 for grid placement over 1,500,000 kWh	€/MWh	234	160	160	160	160	160
Other Charges, Costs, Etc.		0	0	0	0	0	0
Total Annual Margin in € after Main Costs (excluding taxes, disposal, etc.)		15.199.833	19.085.158	25.446.877	6.361.719	12.723.438	3.180.860
OPTION Features		1+2) National Needs Only (Regulation) 1+3) National Needs + Local Needs INTEGRATED PROJECT "HYDROSOLAR"			Local Energy Needs Only (4)	Exceeds Local Energy Needs (5)	Insufficient x Local Energy Needs (6)
PROFITABILITY ANALYSIS (not automatic)	(NPV) at r=4.5%	42.273.591 €	35.336.024 €	47.114.698 €	11.778.675 €	23.557.349 €	5.889.337 €
	(IRR)	>5%	>5%	>5%	>5%	>5%	>5%
	Financ.Repaym. (Breakeven Time) BEP	16th year of operation	16th year of operation	16th year of operation	16th year of operation	16th year of operation	16th year of operation
	Debt Serv. Coverage Ratio (DSCR)	1,54	1,72	1,72	1,72	1,72	1,72
	Deb.Serv. DSCR considering Construction Interests	0,58	0,83	0,83	0,83	0,83	0,83
Option No.	N°	(1)	(2)	(3)	(4)	(5)	(6)
Note	Option No. (1) can only exist in conjunction with No. (3) or at most with No. (2)						

Table 5: Summary 1 – Simulations.

OPTIONS WITH GRID PLACEMENT PRICES PER kWh HIGHER THAN THE CURRENT ITALIAN ELECTRICITY MARKET BUT MORE EASILY BANKABLE - (Summary 2)							
SUMMARY OF THE DIFFERENT OPTIONS PRELIMINARILY CONSIDERED FOR A POSSIBLE HYDROSOLAR POWER PROJECT WHICH ARE SUSTAINABLE UNDER CERTAIN TECHNICAL-ECONOMIC CONDITIONS EXPLICITLY STATED							
Item	Unit of measurement	Hydro 100 MW (1)	Photovolt. 300 MW (2)	Photovolt. 400 MW (3)	Photovolt. 100 MW (4)	Photovolt. 200 MW (5)	Photovolt. 50 MW (6)
Project Team, etc.	(min. x years)	0	0	0	0	0	0
Peak Power	kW	100.000	300.000	400.000	100.000	200.000	50.000
Necessary Area	m^2	0	4.500.000	6.000.000	1.500.000	3.000.000	750.000
Annual Land Fee	€/m^2	0	0,25	0,25	0,25	0,25	0,25
Unit Cost of Plant Investment	€/kW	3470	1100	1100	1100	1100	1100
Plant Investment Cost	€	347.000.000	330.000.000	440.000.000	110.000.000	220000000	55.000.000
Interest rate	(r)	0,045	0,045	0,045	0,045	0,045	0,045
Loan Repayment Years	(n)	12	12	12	12	12	12
Annual Repayment Quota	(A)	38.054.167	36.189.842	48.253.123	12.063.281	24.126.562	6.031.640
Operation Hours 7x365		2555					
Annual producibility per kW	kWh/year kW	2555	1300	1300	1300	1300	1300
Annual Productivity	kWh	255.500.000	390.000.000	520.000.000	130.000.000	260.000.000	65.000.000
Annual O&M fixed costs	€/kW year	50	20	20	20	20	20
Variable Costs	€/kWh	0,002					
Tranche 1	kWh	1.500.000	1.500.000	1.500.000	1.500.000	1.500.000	1.500.000
Unit price Tranche 1 for grid placement up to 1,500,000 kWh	€/MWh	500	300	300	300	300	300
Tranche 2		254.000.000	388.500.000	518.500.000	128.500.000	258500000	63.500.000
Unit price Tranche 2 for grid placement over 1,500,000 kWh	€/MWh	500	300	300	300	300	300
Other Charges, Costs, Etc.,		0	0	0	0	0	0
Total Annual Margin in € after Main Costs (excluding taxes, disposal, etc.)		84.184.833	73.685.158	98.246.877	24.561.719	49.123.438	12.280.860
OPTION Features		1+2) National Needs Only (Regulation) 1+3) National Needs + Local Needs INTEGRATED PROJECT "HYDROSOLAR"			Local Energy Needs Only (4)	Exceeds Local Energy Needs (5)	Insufficient x Local Energy Needs (6)
PROFITABILITY ANALYSIS (not automatic)	(NPV) at r=4.5%	419.341.235 €	374.794.129 €	499.725.505 €	124.931.376 €	249.862.753 €	62.465.688 €
	(IRR)	>10%	>11%	>11%	>11%	>11%	>11%
	Financ.Repaym. (Breakeven Time) BEP	7th year of operation	9th year of operation	9th year of operation	9th year of operation	9th year of operation	9th year of operation
	Debt Serv. Coverage Ratio (DSCR)	3,36	3,23	3,23	3,23	3,23	3,23
	Deb. Serv. DSCR considering Construction Interests	1,23	2,34	2,34	2,34	2,34	2,34
Option No.	N°	(1)	(2)	(3)	(4)	(5)	(6)
Note		Option No. (1) can only exist in conjunction with No. (3) or at most with No. (2)					

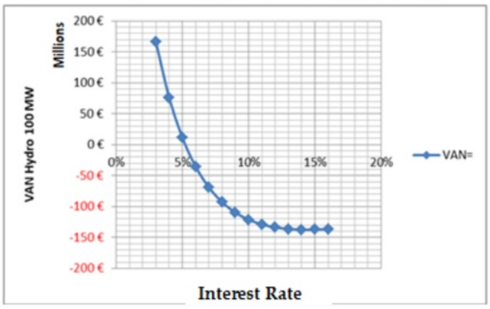
Table 6: Summary 2 – Simulations.





HYDRO 100 MW - Interest Rate 4.5%
Average kWh production cost €171/MWh – Selling Price €230/MWh
Close to market prices – "BANKABLE" with difficulty

HYDRO 100 MW - Interest Rate 4.5%
Average kWh production cost €171/MWh – Selling Price €500/MWh
Far from market prices – "BANKABLE"



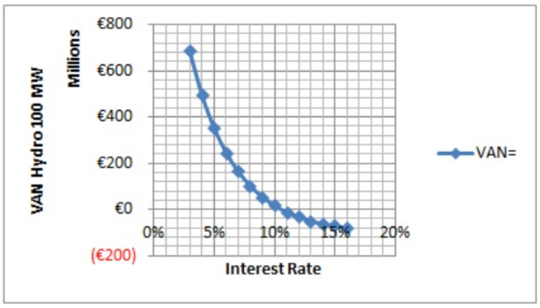
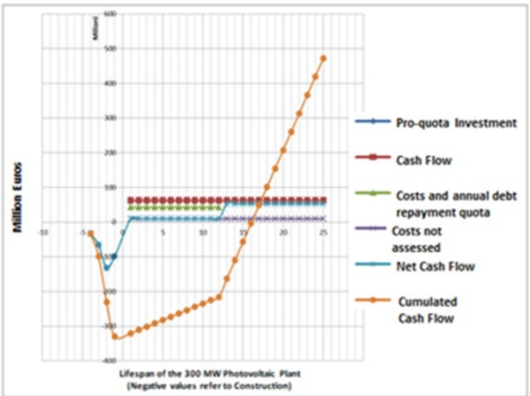
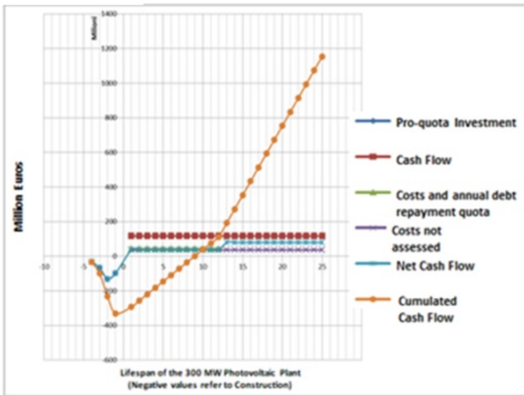


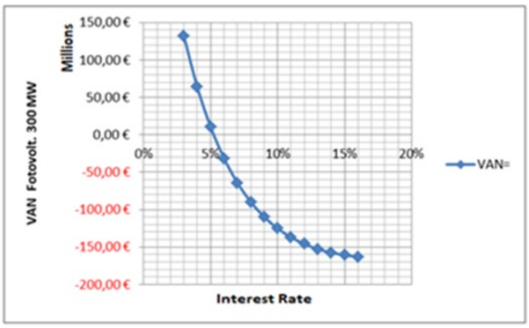
Figure 8: Graphical results of selected Indicators for Hydro Power Plant 100MW.





PHOTOVOLT. PLANT 300 MW - Tasso di Interesse 4,5%
Cost per kWh: €111/MWh - Selling Price €160/MWh
Close to Market Prices – "BANKABLE" with Difficulty

PHOTOVOLT. PLANT 300 MW - Tasso di Interesse 4,5%
Cost per kWh: €111/MWh - Selling Price €300/MWh
Far from Market Prices – "BANKABLE"



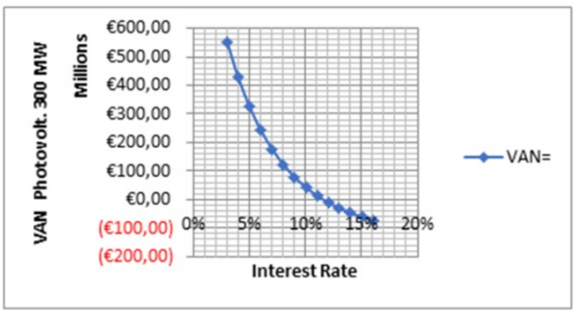


Figure 9: Graphical results of selected Indicators for PV Plant 300MW.

2.7 Some technical aspects to consider when finalizing the project

The aspects to be considered in the engineering and design phase are both of a strictly technical nature as well as financial nature, including the possibility of using ETS for project financing purposes[23-28] (see Fig. 10 and Table 7 below, along with the online wiever https://sandbag.be/carbon-price-viewer/).

Figure 10: CO_2 price trend (in €/t) in the first ten months of 2021.

Item	Unit of Measurement	Hydro 100 MW (1)	Photov.300 MW (2)	Photov.400 MW (3)	Photov.100 MW (4)	Photov. 200 MW (5)	Photov.. 50 MW (6)
Annual producibility per kW	kWh/year kW	2555	1300	1300	1300	1300	1300
Annual Productivity	kWh	255.500.000	390.000.000	520.000.000	130.000.000	260.000.000	65.000.000
Average Reference Value of CO2/kWh	kg of CO_2/kWh	0,53	0,53	0,53	0,53	0,53	0,53
Specific estimate of CO2 produced by each option in its life cycle	kg of CO_2/kWh	0,106	0,053	0,053	0,053	0,053	0,053
Total estimated CO2 avoided by each option in each operating year	t (Tons)	108.332	186.030	248.040	62.010	124.020	31.005
Useful Life	Years	30	25	25	25	25	25
Estimated CO2 avoided by each option in its life cycle	Total t (Tons)	**3.249.960**	**4.650.750**	**6.201.000**	**1.550.250**	**3.100.500**	**775.125**
Official average value of CO2 emission permits (in the first 10 months of 2021)	Euro/Tonn.	44	44	44	44	44	44
Avoided cost for CO2 emission permits (2021 basis)	**Millions of Euro**	**143**	**205**	**273**	**68**	**136**	**34**

Table 7: ETS ”WHAT IF” estimate: Given an average trend in the cost of CO_2 in a given period, the table shows the estimate of its avoided cost for the purposes of tradable emission certificates.

For example, regarding the optimization of the volume and positioning of the hydro reservoirs based on the duration of the pumping and regulation service; as well as for the choice of the type of hydraulic turbine based on head and flow rate refer to Fig. 11 and Fig. 12. Obviously, it is advisable to optimize projects with the highest possible geodetic heads to reduce the costs of reservoirs, penstocks, machinery, etc. Small heads with high flow rates may generally influence the type of system and affect investment costs. Furthermore, where one wishes to prioritize the reliability of the pumping service and the versatility of the plant, one could consider distributing the power across multiple plant sections: for example, instead of a 100 MW hydroelectric plant, one could consider two 50 MW sections or four 25 MW sections, provided that the costs allow it.

The length of the penstock along the geodetic head can cause water hammer in the event of a sudden closure or interruption of water flow and may also require, as a mitigating measure, a piezometric and damping system, with implications on investment costs.

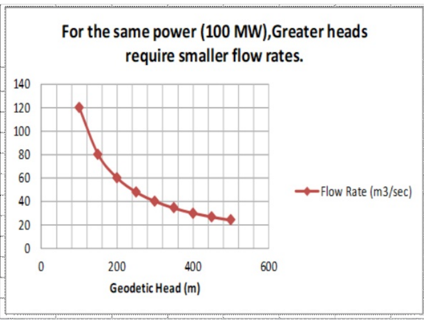
The development and implementation programs also need to be optimized, for which two preliminary proposals have been reported below, drawn up separately in Fig. 13 and Fig. 15, respectively for the hydroelectric part and for the photovoltaic part. For a 100 MW hydroelectric plant, EIA data suggests a five-year timeframe, from the start of on-site construction. However, in practice, there may be specific circumstances (as has occurred in other large hydroelectric plants in Italy and elsewhere) that could have extended the timeframe. Typically, it is authorization processes (permits and licenses), whether institutional, external, or internal, that can create delays, as well as complications with on-site civil engineering work, or delays in the fabrication of components in the workshop. Obviously, delays that occur after construction has begun, negatively impact the project's financial costs, not only because they increase interest on the financing received, but also because they delay the plant's entry into commercial service and therefore impact the Debt Repayment Service. In short, a hydroelectric plant's program is longer and exposes it to greater economic, financial, and other risks, which must be appropriately considered in advance. Taking into account the greater difficulties that are objectively encountered in the construction of systems in caverns rather than at the foot of the dam, the preliminary reference of 3 years of development and design + 9 years of construction for a cavern solution as in Fig. 13 and Fig. 14. For the solution at the foot of the dam it can be preliminarily assumed that the construction program is reduced from 9 to 6 years, and if the development and design program remains at 3 years, the total is 6 + 3 = 9 years.

The basic assumptions for a timeline for a large photovoltaic system (≥ 100 MW) are as follows:

a) - a large photovoltaic field does not necessarily have to be built on a single, seamless area; that is, it may also consist of several sub-fields located in different parts of the same territory (e.g., different municipalities in the same province), but part of the same project and essentially using the same local electricity grid to feed their production into the grid. Obviously, in this case, the existence and availability of logistical infrastructure must be verified for each sub-field;
b) - this means that since a PV plant is a modular project that can be reduced to site preparation, civil engineering, and assembly of supporting structures and panels, it is possible to work simultaneously, practically in parallel, on multiple sub-fields (differently located), providing in appropriate measure the necessary manpower and resources on each sub-field;
c) - This allows us to assume that for a large project (e.g., ≥ 100 MW), construction times – as a first approximation – should not vary significantly with plant size. Therefore, we can preliminarily assume a construction time of no less than approximately 3 years for the typical 150 MW plant taken as a reference from EIA data for on-site activities, excluding the part concerning development activities and testing, measurement, and inspection for the plant's commercial start-up.
d) - Subject to refinements during the design phase, it seems reasonable to preliminarily assume the construction schedule shown in Fig. 15.

For simulation purposes, the estimated costs for each type of plant have been uniformly distributed across the respective timescales assumed in the aforementioned programs in order to calculate the indicators selected for evaluation shown in the various graphs and tables. By refining the design and planning to achieve a preliminary uniform distribution of costs over time, more targeted solutions can be adopted.

Plant Power	Hours of Service	Plant Efficiency	Specific Weight H_2O	Geodetic Head	Flow Rate	Total Volume Basins
(kW)	(h)	/	(kg/m³)	(m)	(m³/sec)	(m³)
100.000	7	0,85	1.000	100	120	3.024.000
100.000	7	0,85	1.000	150	80	2.016.000
100.000	7	0,85	1.000	200	60	1.512.000
100.000	7	0,85	1.000	250	48	1.209.600
100.000	7	0,85	1.000	300	40	1.008.000
100.000	7	0,85	1.000	350	34,3	864.000
100.000	7	0,85	1.000	400	30	756.000
100.000	7	0,85	1.000	450	26,7	672.000
100.000	7	0,85	1.001	500	24,0	604.196



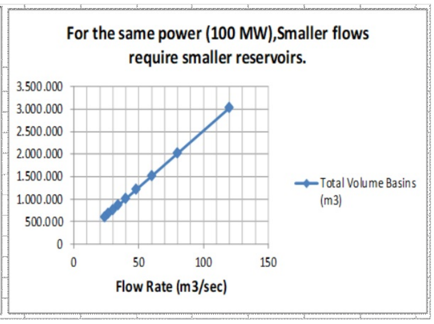


Figure 11: When dealing with Artificially Created Heads: Optimize Projects with the highest possible geodetic heads to reduce the costs of Basins, Penstocks, Machinery, Etc. – Small Heads with High Flow Rates typically increase Investment Costs.

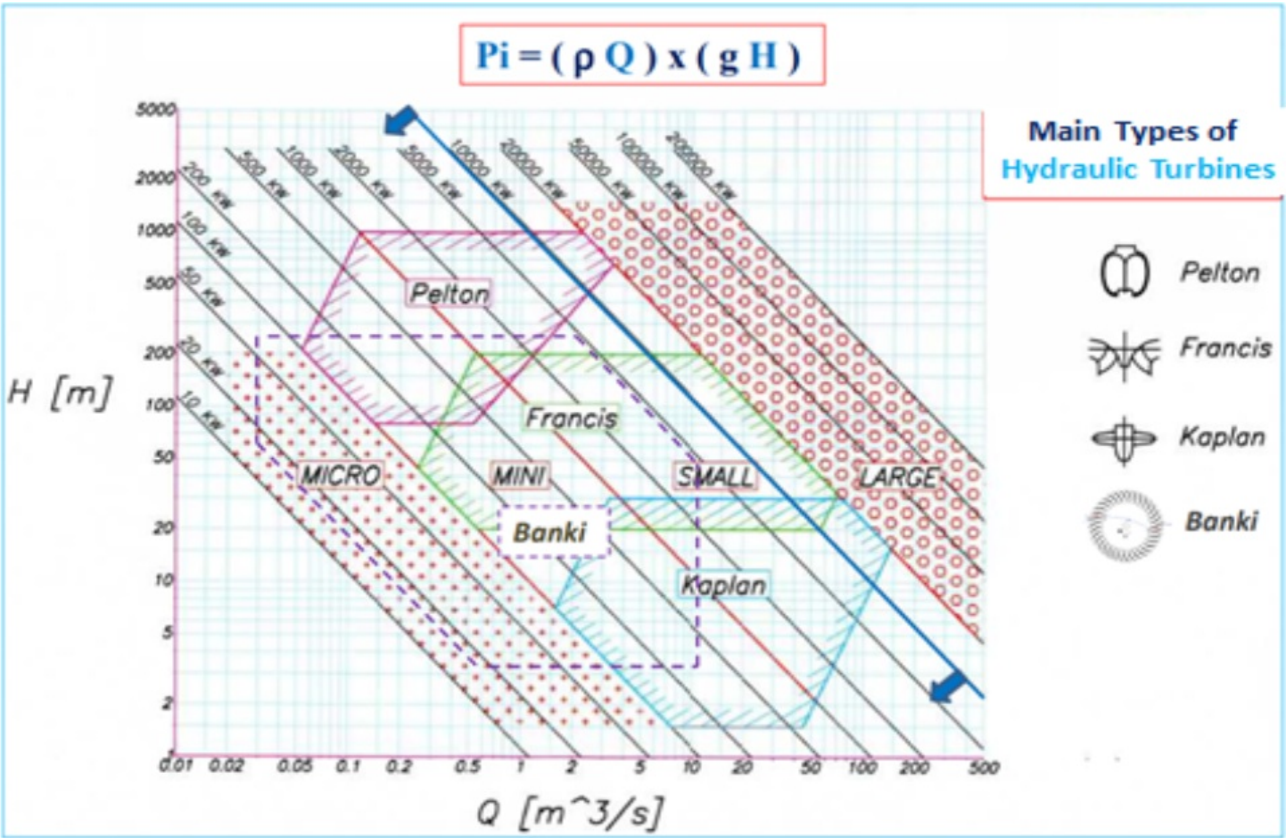


Figure 12: Choice of hydraulic turbine type according to head and flow rate.

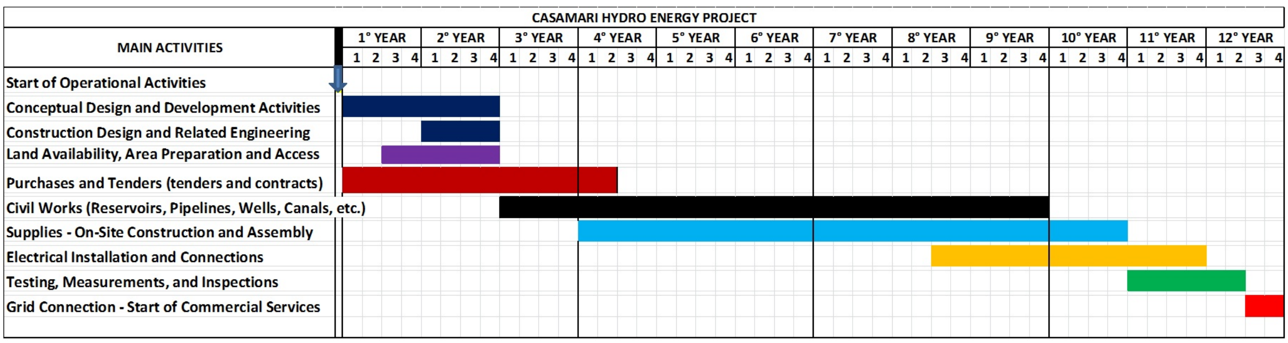


Figure 13: An indicative general implementation program for the Hydro part - (Preliminary reference for the Cave Solution as in the figure below)

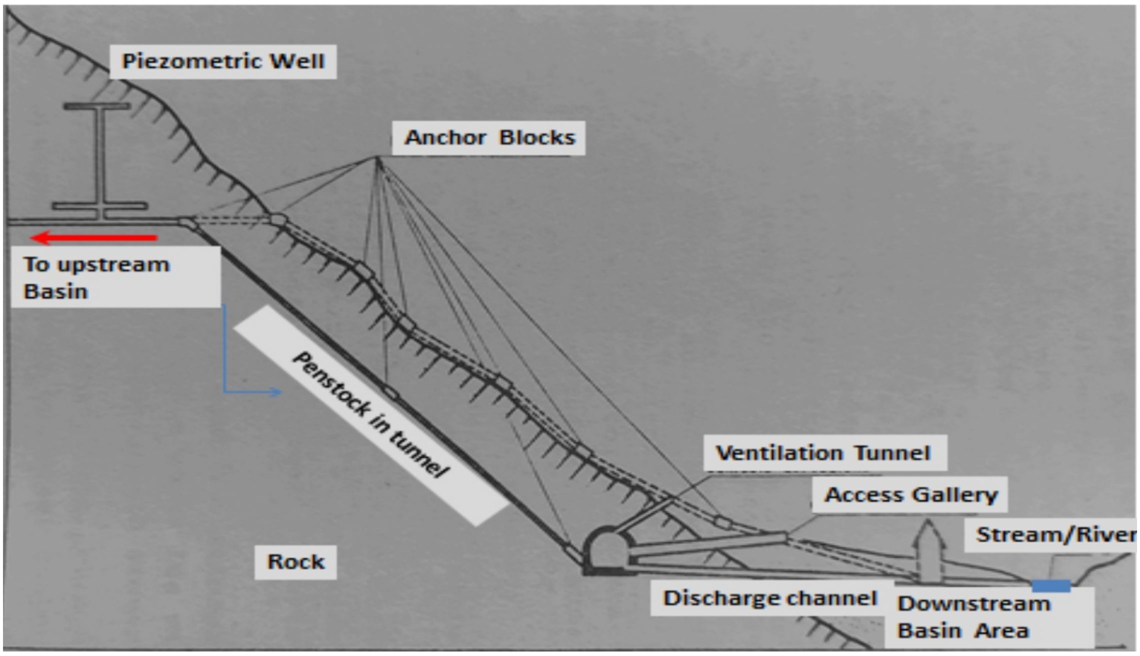


Figure 14: Cave solution vs. at the foot of the dam solution.

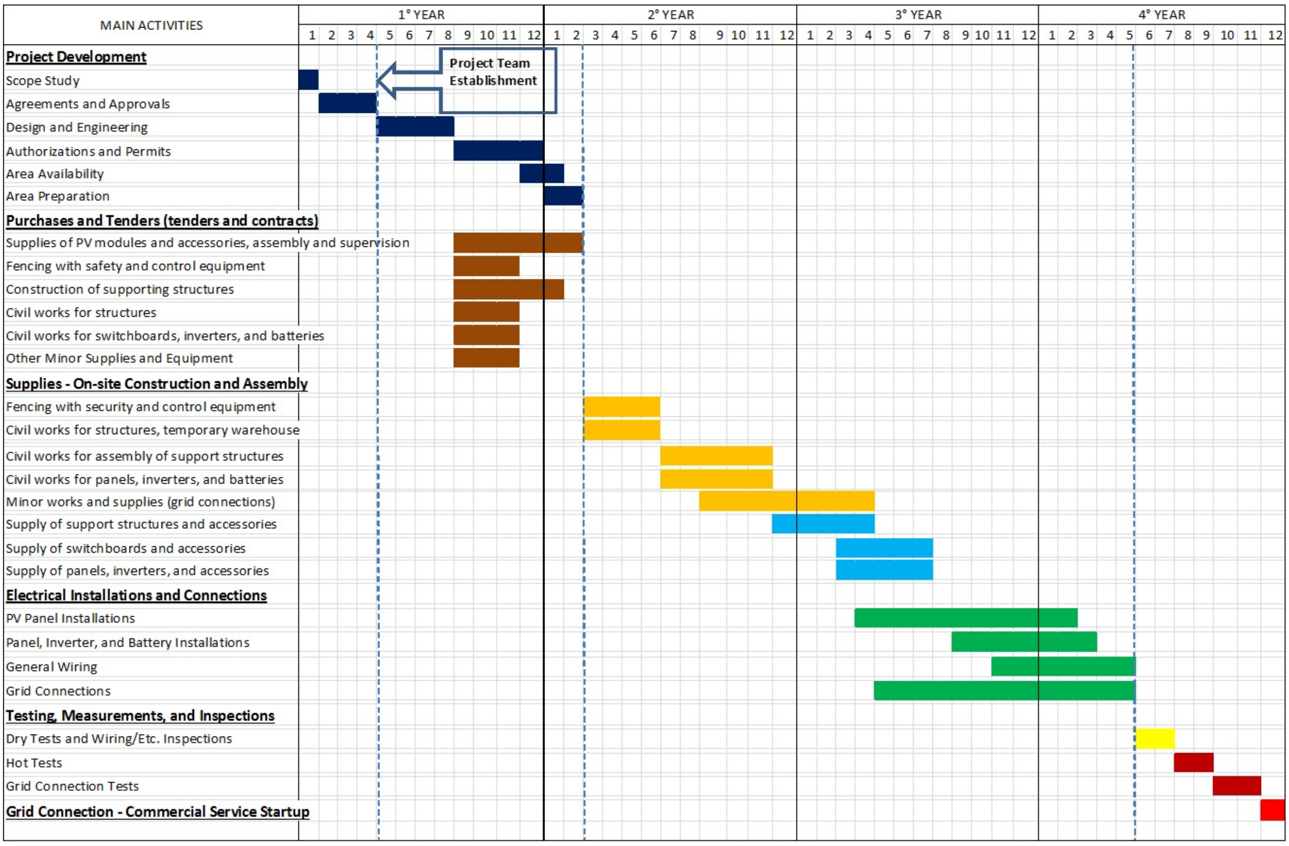


Figure 15: An indicative general implementation program for the photovoltaic part.

2.8 A general note on cost estimation according to the literature

At this point it appears evident that the reliability of an estimate for a project is higher the more refined the development phase is, that is, the more one moves towards a final "bankable feasibility" study complete with engineering project, calculations and necessary drawings, with business planning and profitability and risk analysis (for risk analysis see § 11). Below is an excerpt from the mentioned UNIDO Manual for the Preparation of Feasibility Studies for Industrial Projects. It can be seen that in the initial study phase, the margin of error can be as high as ± 30%, and in the "bankable feasibility" phase, where the estimate is calculated based on a bill of quantities derived from the basic engineering design, it is reduced to ± 10%. The same Manual lists the costs of pre-investment studies expressed as percentages of investment costs, which are approximately as follows:

- 0.2-1.0 percent for an opportunity study
- 0.25-1.5 percent for a pre-feasibility study
- 1.0-3.0 percent for a feasibility study for small and medium-sized enterprises (SMEs) industrial projects
- 0.2-1.0 percent for large industries or large projects with sophisticated technologies or challenging markets

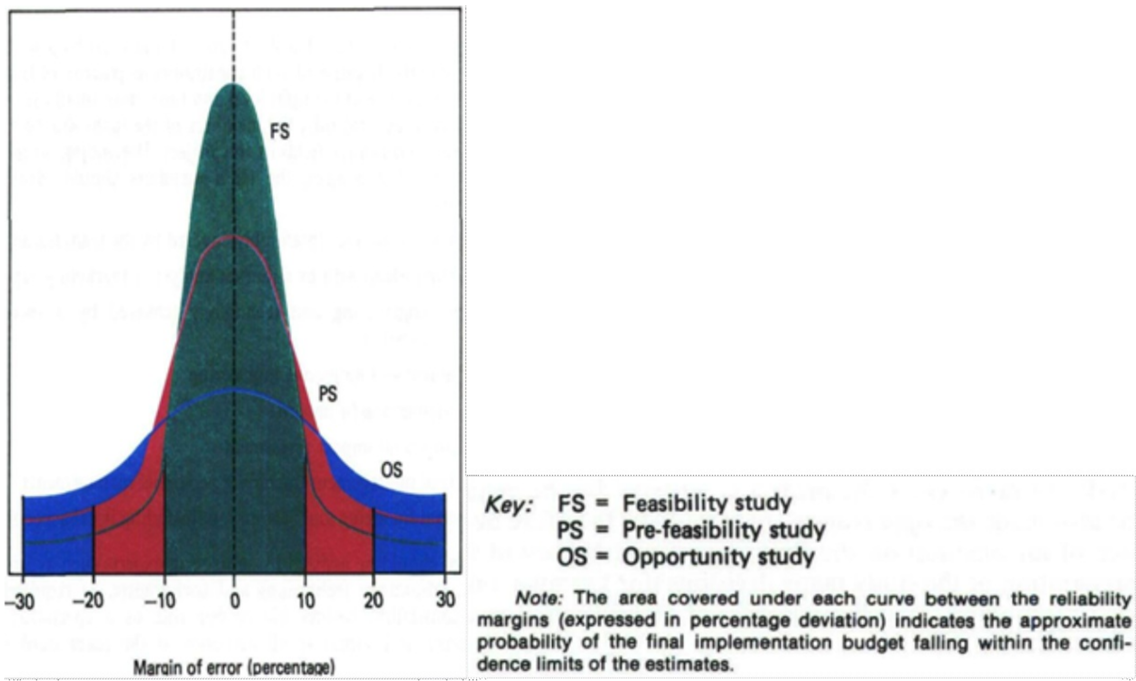


Figure 16: Source: https://www.unido.org/sites/default/files/files/2021-02/manual_for_the_preparation_of_industrial_feasibility_studies.pdf

2.9 For an Environmental Impact Assessment

A 2019-2021 UNECE (United Nations Economic Commission for Europe) study [29], often cited as a reference but still in draft form (the link to which is included in the references), examines the entire "life cycle" of various electricity generation options. It confirms a lower environmental impact and higher conversion efficiency for all renewables and nuclear power compared to fossil-fueled plants. Regarding hydroelectric power, in particular, plants with a capacity of up to 360 MW appear to be particularly noteworthy. Only Figures 17 and 18, which demonstrate this, are shown below in excerpts, but the study is much more comprehensive and contains significant elements worthy of broad sharing particularly in case of comparative environmental impact assessment... (When analyzing the graph, it may be useful to remember that 1kWh = 3.6 MJ.).

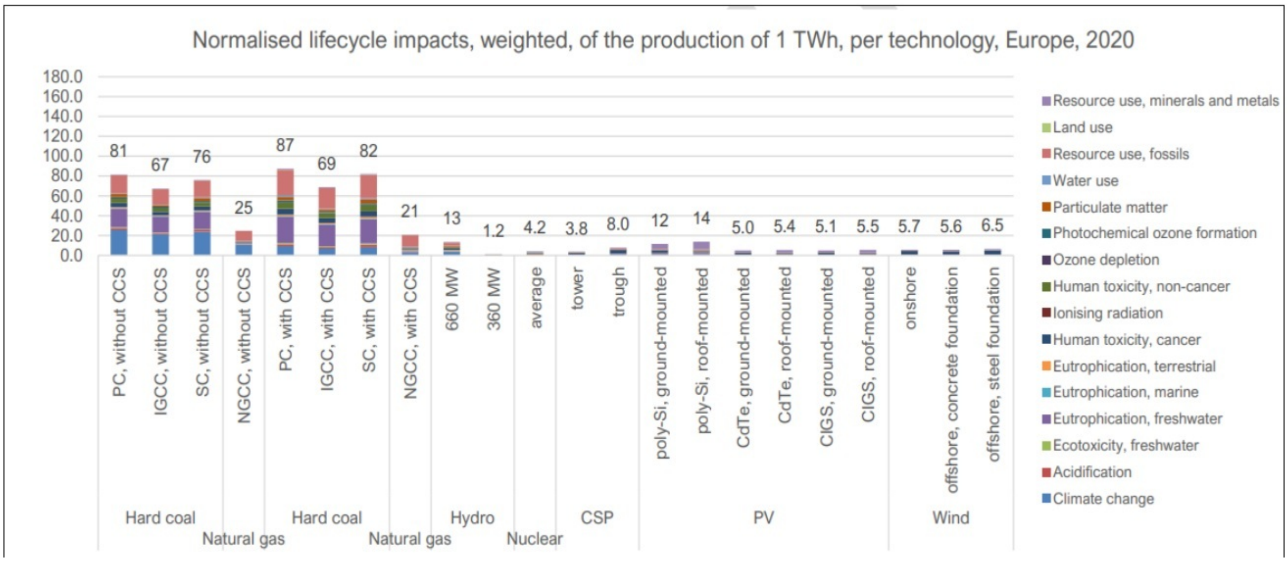


Figure 17

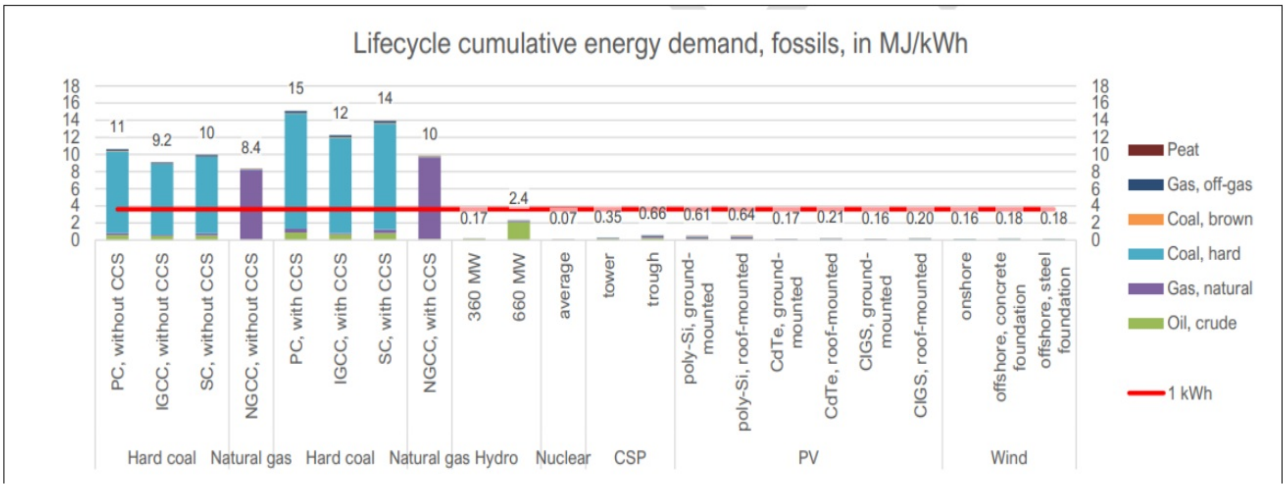


Figure 18

2.10 Need for risk analysis and evaluation for possible mitigation

It's no coincidence that among project risk assessments, the most common ones include sensitivity assessments for potential cost and schedule overruns (cost & schedule overruns), as well as the risks of interest rate fluctuations on financing. Furthermore, it's not just risks that directly impact costs and schedules (due to difficulties with on-site work or in manufacturing plants) that need to be considered, but also those of a more technical nature, such as the following:

- - basic engineering risk: this can be mitigated by using qualified and certified designers with proven and consolidated experience, i.e., those who have successfully designed similar systems. Contractual arrangements such as "turnkey" or BOT (Build Operate & Transfer), or even insurance-based ones, can certainly help mitigate this risk, but in the event of an adverse event during construction, a contractual liability may need to be enforced through legal means; thus, the project risks being damaged in any case while awaiting court decisions;
- construction risk: what has been said for the design risk applies, but applied to certified and qualified contractors and/or suppliers, EPC Contractors, who have already built similar systems;
- geological risk: which can be mitigated by resorting to preventive location studies and on-site investigations (geological, geognostic, geotechnical, hydrogeological analyses, etc.) which are also necessary in the design phase and already partially outlined in a desirable Preliminary Geological Report;

- seismic risk: the same applies as for geological risk;
- hydrogeological risk: the same applies as for geological risk.
- To properly extend the review, it is important not to forget:
- operational risks: these are encountered during the operation of the plant after commercial start-up, but before the plant has been fully repaid, for example, due to prolonged downtime due to service disruptions, interruptions, maintenance, defects, hidden faults, etc.;
- reimbursement risks: these are linked not only to potential fluctuations in the financial market, but also to legislative changes that impact the plant under construction or already built;
- political, social, and environmental risks: these were often overlooked in the past because they could not be measured except qualitatively. Today, however, through multidimensional data analysis, these too are beginning to appear as measurable entities;

Ultimately, risks are mitigated through expertise and foresight in planning and design, and where possible by transferring them to others through insurance (e.g. all-risk policies) or contractually, which not only leads to increased project costs, but could also lead to endless litigation or legal disputes and arbitration proceedings in the event of the actual occurrence of that risk, so that the chosen remedy may become worse than the evil it was intended to cure.

3 Conclusions

This review of an initial preliminary study from 2023 (with constant-price valuations) for a general overview of the topics and systems discussed herein was conducted with the aim of providing, through excerpts, a broader and more mature view of certain aspects, which are hoped for further research, as well as industrial development. This 2023 study, previously unpublished, also contains the simulations reported here, in part, on the six possible system options studied for a specific project. The project itself is still under development and involves several municipalities in southern Lazio. Obviously, those presented here are only approximate and indicative results, and their approximation errors can only be reduced by refining the analysis and progressing through the various project development phases. This requires an initial and comprehensive opportunity/scope-study, a subsequent pre-feasibility study, and finally a bankable feasibility study, complete with basic design and engineering, as well as analyses to reduce risks and secure the necessary financing for construction on a specific and suitable site. Planning accurately all necessary licensing and permits is essential to avoid time and cost overruns.

It can be said that similar projects, inspired by the above criteria, are highly recommended, given the high energy dependence of the EU, and Italy in particular (72% instead of 78% is nowadays an objective figure). It is also objective that two 50 MW plants, with overlapping production, one wind and the other photovoltaic, together produce as much as an ideal plant of another type operating at a power of~ 25 MW (see Rivista Energia 2021 04). Due to their intermittency, wind and photovoltaic create problems of regulation and grid stability, especially in an interconnected grid like the European one, where ”a problem with energy exchanges in the Balkans has repercussions on the entire continent” (see RSE research cited). But such arguments cannot be limited to specific or local energy needs and must rather be extended to the planning of global needs.

Areas with limited interconnection or isolation, where significant expansion of photovoltaic and wind power is desired (e.g., Sicily, but not limited to it), should focus more attention on grid regulation and stability. Given a total available power of “x” GW (not fully utilized, due to its ”fossil” nature), a total of ”x” GW cannot be planned from wind and photovoltaic source, which are intermittent in production. Under such conditions, GRID AND ELECTRICITY SERVICE STABILITY is unlikely to be achieved, and a specialized analysis of the specific electricity system and its grid is to be considered mandatory.

However, by overcoming the difficulties that emerge, we can reduce the high energy dependence by means of solar energy, especially with photovoltaic systems in suitable and selected areas (e.g., in central and southern Italy), as per the optimal zones highlighted on the map of Italy in the Appendix 1. But at the same time is compulsory to facilitate grid regulation and stability at the expense of the sun with pumped hydroelectric plants, with daily service (for a number of hours depending on the case, e.g. 7 hours) and hydro-reservoirs of adequate volume for the extractable power and the possible flow rate and available head. Pumping must be powered by photovoltaic systems that feed energy into the grid during the day, to be taken from the grid for pumping during the night (10-12 hours). In practice, the difference in day/night demand would be exploited to minimize the need for storage.

Fig. 7 shows the conceptual scheme of the integrated plant. It is a pumped-storage plant with reservoirs for daily service (≥ 1.5 Mm3). The upper reservoir is filled at night and emptied during the day; vice versa, the lower reservoir. A 300 MW photovoltaic system can power a 100 MW pumped-storage hydroelectric plant with a power ratio of approximately 3. In other words, the photovoltaic system and the hydroelectric system are both connected to each other and to the electricity transmission grid and the ratio of their capacity has to be~ 3.

For a 100 MW pumped-storage plant, a program with 3 years of development and design is preliminary assumed, and 9 years of on-site construction for an underground power plant, which can be reduced to 6 years for a dam-based plant, where possible, according to geology and other characteristics of the site. We have not gone into detail here because it depends greatly both on the type of project and the site. For the 300 MW photovoltaic plant, a program with one year of project development and three years of on-site construction is assumed. For a 400 MW plant, rather than a 300 MW plant, it can be assumed that the program will not vary significantly, as the construction period is broad and essentially linear. There-fore, the duration depends only on the resources employed.

The table and graphs in Fig. 11 show that, for the same power output, projects with high geodetic heads and low flow rates should be favored, as this reduces the volumes of the upper and lower basins, pipe-lines, and turbine-pumps used, thus reducing investment costs, facilitating the project's bankability, and containing production costs. This results in lower prices for energy fed into the grid.

For the various plant options considered in the aforementioned 2023 study, the data used and the results are reported in Summaries 1 and 2 (Tables 5 and 6, respectively). Option 1 can only exist in combination with 2 or 3, for obvious power reasons. An economic analysis and a simulated profitability analysis were performed for each option. In the absence of a real engineering project, the overnight costs provided by EIA (US Administration) were used. Therefore, the results in summaries 1 and 2 and the other tables are only preliminary indicative. To build 100 MW of hydroelectric power (with nighttime pumping, 7-hour daytime service,~ 1.5 Mm3 of reservoir), 300 MW of photovoltaic energy is required on 450 hectares of land (equivalent to an area of 2.1x2.1 km). The production costs calculated in Summary 1 are close to market costs, and therefore the market prices of the energy produced make bankability difficult, although the loan repayment service appears assured (but with high risk and low profitability).

For the Profitability Analysis, four typical project evaluation indicators were calculated: NPV, IRR, BREAK-EVEN (Break-Even Point), and DSCR (Debt Service Coverage Ratio). These indicators fall on values that can make the project bankable if the energy produced is placed on the grid at prices higher than the current market. A breakthrough in this regard can be achieved both by the geological and engineering optimizations achievable with the project's development, and by the careful and appropriate functioning and use of ETS (Emission Trading System) emission certificates for the CO_2 avoided by the project itself.

It should be noted, however, that this is a preliminary opportunity study based on overnight reference costs, subject to possible error margins in accuracy, making the results indicative and not exhaustive. Nonetheless, we can speak of a contradiction between market energy prices and project bankability, as results show. Favouring one harms the other, and vice versa. This emerges clearly from the simulations as well as intuitively. The contradiction between Market and Bankability mentioned above can be seen in the market price values in Summaries 1 and 2, or visually in the graphs shown. They refer to the two main options examined, but the situation is the same for all options considered.

The graph in Fig. 10 shows that for most of 2021, the market value of CO_2 fluctuated between 30 and 60 €/t. On average, it was~ 44 €/t over the period considered. This value fluctuates constantly, having subsequently exceeded~ €100/t, and the hypothesized use to facilitate the type of projects proposed here implies a stabilization of this value, which is not yet realistic.

If we assume a stable, rather than volatile, average CO_2 price of around~ €44/t, it can be calculated that the ETS provides renewable energy plants with values that, cumulated over the entire life cycle of the plant (which in this case is 30 years for hydroelectric and 25 for photovoltaic), represent significant amounts useful for financing the plants themselves. This can significantly mitigate the conflict noted between project bankability and the free electricity market. But is it possible to stabilize the market price of CO_2 [30]?

If it were not possible to stabilize and make the Emissions Trading mechanism reliable (with almost zero volatility), its contribution to a project's financeability would become negligible, unless a debt contracted can be repaid with "volatile" ETS certificates. Therefore, these types of renewable energy projects can only be developed through a public institutional financier.

Now, one might object that: for hydro-solar power projects, the costs are known, but are the benefits also known? We can take this opportunity to recall them as follows:

- i. they reduce energy dependence and promote grid regulation and stability.
- ii. they originate and develop locally, without geopolitical dependencies.
- iii. they are anchored to the territory and can create "energy communities and collective self-consumption."
- iv. they are labour-intensive, favouring industrial enterprise over finance.
- v. they have a high local impact of the investment.
- vi. they integrate photovoltaic and hydroelectric power, meeting sustainability and energy transition criteria.
- vii. they "artificially" alter the hydroelectric potential of a region, provided it still has high elevation up-stream and a river downstream, as well as sufficient land suitable for photovoltaic power.
- viii. they allow for the generation of green certificates for emissions trading on the stock exchange for discrete portions of the investment cost, which could be used to repay the project.

If the objection is that they consume a lot of land, and if the land is available and located on underused areas or abandoned infrastructure, the final question is: why oppose renewables?
From 2014 to 2023, installed photovoltaic power grew at a rate of approximately 12 GW per decade, with solar electricity production reaching 27.5 TWh/year. This is still far from the trend needed to reach the 2030 targets. Indeed, photovoltaic power will need to generate an annual output of around 100 TWh by the end of the decade, thus avoiding the need to import 20 billion cubic meters of gas annually. Approximately 70 TWh remain uncovered, which is unlikely given that solar generation in Italy has increased by just 5.8 TWh/year, partly due to the constraints imposed by national and local policies, according to some observers who perhaps have a point.

The entire Italian high-voltage grid (380 and 220 kV) is highly interconnected to the European grid, but pumped storage hydraulic power has remained essentially at~ 1.5 GWe, or less than 1% of Italy's gross efficient power of 123.3 GWe. All this while intermittent photovoltaic and wind power is rapidly expanding. Sicily, an offshoot of the mainland's grid interconnected at only one point, deserves attention for grid regulation and electricity service stability.

The global situation of installed electrical power and considering the envisaged needs to expand AI and IT and data centers necessary [31], suggests that we are far from achieving the transition and therefore sustainability goals; and we continue to ignore the fact that renewables produce intermittent energy and that 50+50 MW of wind and photovoltaic combined equals 25 MW of continuous power.

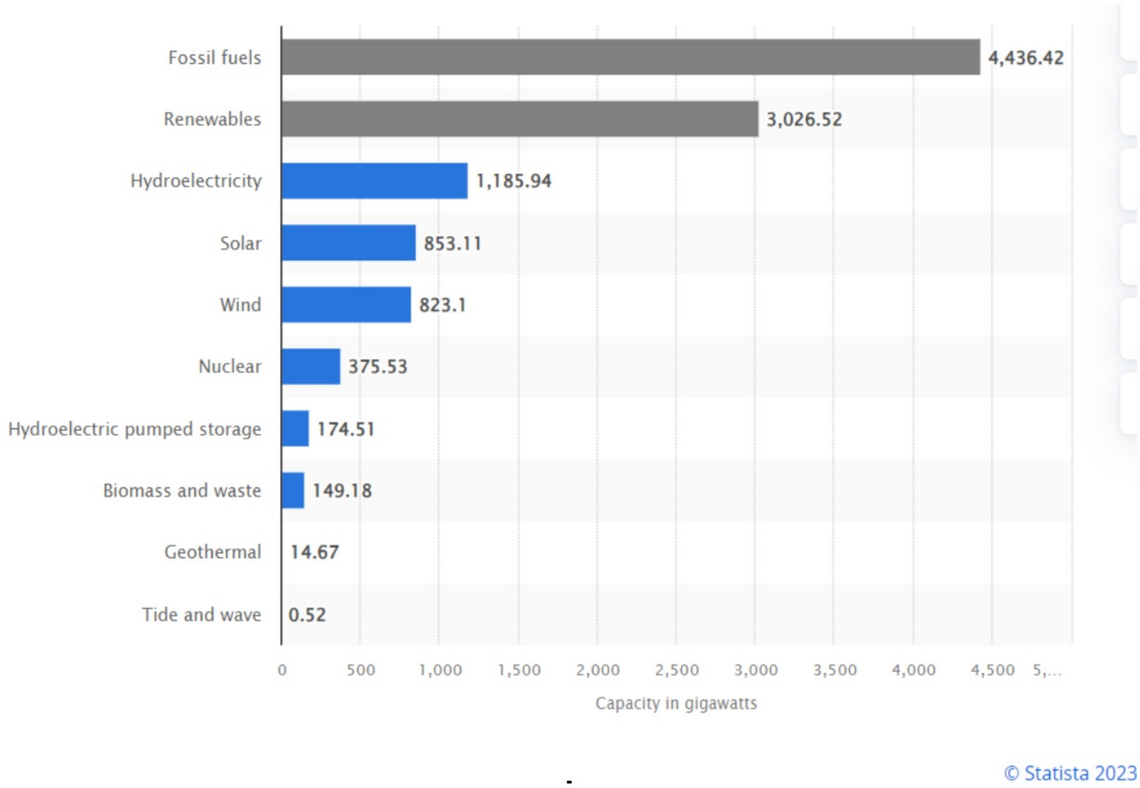


Figure 19: Global installed power 2023.

If it is not possible to stabilize and make the Emissions Trading mechanism reliable (with virtually zero volatility), thereby making its contribution to the financeability of a project, its role in this case becomes secondary and negligible for expanding renewable energy. In this case, these types of renewable energy projects could only be developed and implemented through a public institutional founder. This is all the more necessary considering that climate change, whether caused by human or natural causes, along with polluting emissions, especially in the form of fine and inhalable particulate matter (residual carbon from combustion, asbestos, rock or glass flour or fiber, interstitial radon, etc.), impacts not only the health of the planet but also the ecosystems that inhabit it, including human and metropolitan urban ecosystems.

Reduced biodiversity and the disappearance of living species are also strongly correlated with change and emissions. Under such conditions, mitigation and remediation activities cannot be viewed simply as business opportunities for capital; even if sacrosanct, they take second place to the restoration of health, and the service aspect prevails. In such cases, if anything, the return on capital takes on the meaning of efficiency in the policies and methods adopted. And this also applies to the regulatory service role that hydrosolar plants can play.

The territory we live on is a resource, and preserving it is a challenge. Becoming its custodians is neither easy nor rewarding, but it is an attempt to be accomplished for good sake, especially at a time when politics speaks on command and institutions - including those protecting citizens and consumers - remain silent, ignoring the possible information catastrophe mentioned above and related to AI/IT energy needs.

Acknowledgments

Special thanks go to Geologist Emiliano Cinelli, not only for his suggestions and the discussions we had together on the potential project envisioned here in an area identified in the municipality of which he is Mayor, but also for his sensitivity to the sustainability issues addressed here for the benefit of local populations, possibly to be brought together in self-production and consumption communities as discussed in this work. Thanks also to Industrial Expert Fernando Ciardi and Geologist Tommaso Morelli for their contributions to the development of a preliminary evaluation study for a potential project of the type proposed here, within the Lazio Region. Much of the information reported here was extracted from this ongoing study after revising it. Thanks also to ChatGPT for its searches, which was instrumental in compiling some parts (some of the Pm^2.5 graph/table/references. Appendix 2) in this document.

Appendix 1: Producibility in different Italian Regions

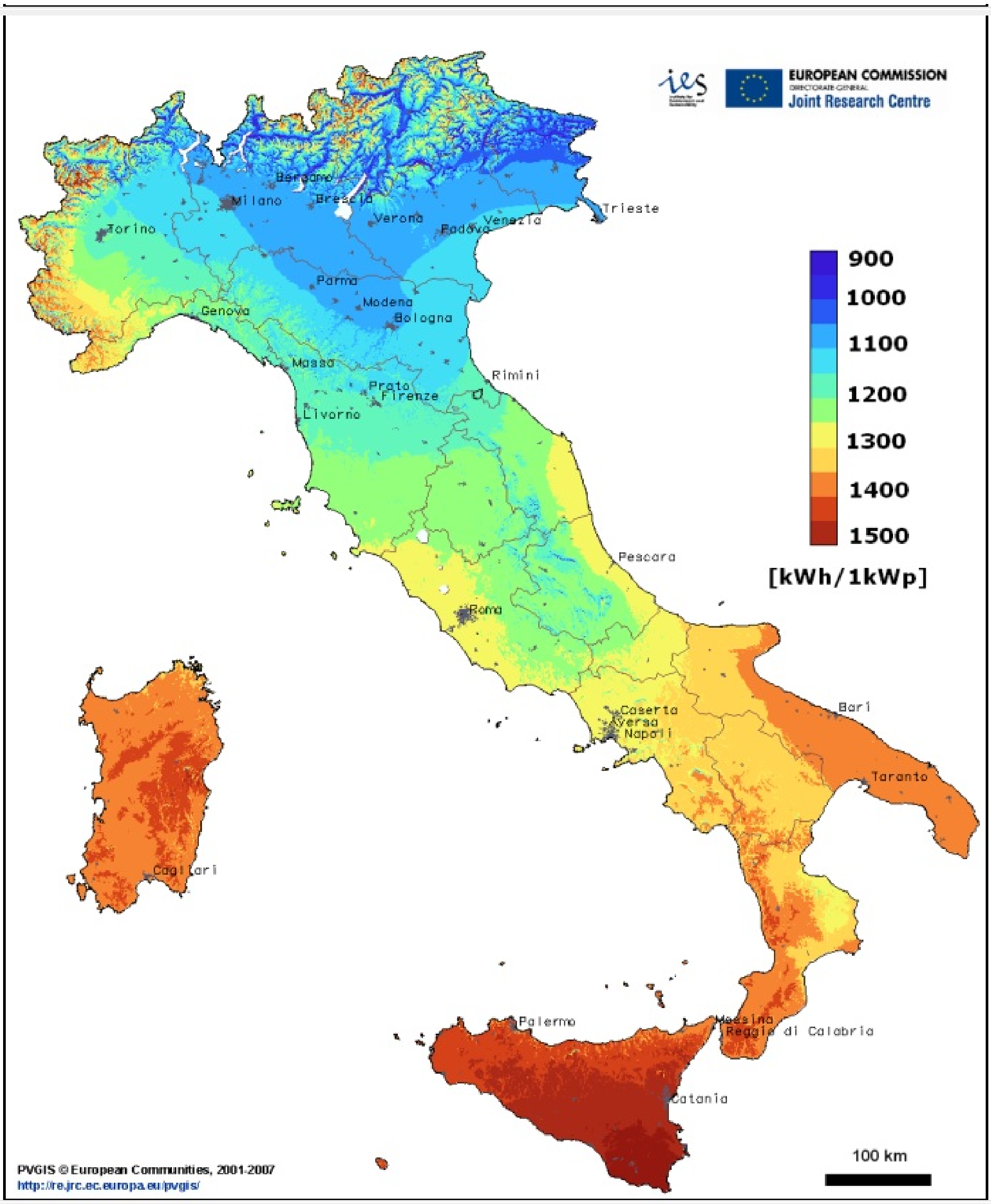


Figure 20: Annual production in kWh/kWp in different areas of Italy (Source: EU/JRC)

Appendix 2: Radiative Limit (Simpson–Nakajima Limit) and the Runaway Greenhouse Effect (Source: Deep Search)

The radiative limit (or Simpson–Nakajima limit) is the maximum flux of outgoing infrared radiation that a water-vapour–rich atmosphere can emit into space. Beyond this limit, an increase in surface temperature no longer increases thermal emission: the planet enters a runaway greenhouse regime. Although the concept was introduced in the 1960s–70s by Simpson, Komabayashi and Ingersoll, later studies quantified its value for Earth's conditions.
Kasting (1984) and collaborators used a one-dimensional radiative–convective model for Earth: they increased solar flux up to 1.45 S_0 (where S_0 is the present solar constant) and obtained surface temperatures up to~ 111 ^{0}C, without yet reaching runaway. Kasting (1988) estimated the critical flux for runaway at around 1.4 S_0, yielding very high equilibrium surface temperatures. Nakajima et al. (1992) formally defined the tropospheric radiative limit, finding that for a fully saturated H_2O atmosphere, outgoing longwave radiation (OLR) asymptotically approaches~ 280–310 W/m^2. Modern spectral analyses confirm that the maximum thermal emission of a humid Earth atmosphere is on the order of~ 280 W/m^2 , regardless of surface temperature increases. Classical work (1980s–1990s): Kasting (1984, Icarus) used a 1D saturated, cloud-free model and found that at 1.45 S_0 surface temperature reached 111 ^{0}C . In his Earth/Venus study (Kasting 1988, Icarus) he reported that complete runaway required~ 1.4 S_0, producing surface temperatures exceeding 1500 K . Nakajima et al. (1992) connected these analyses to the theoretical limit: OLR "saturates" when the convective atmosphere follows the saturated vapor curve. Pollack (1971) had already suggested an OLR cap near 280–300 W/m^2. Kasting also showed that a "moist greenhouse" would occur well before full runaway: even at modest increases of tens of degrees, water vapor invades the stratosphere. Recent research: Colleen Goldblatt et al. (2013, Nat. Geosci.) performed high-resolution radiative calculations and found the thermal radiation limit of Earth's humid atmosphere to be 282 W/m^2 . This implies Earth would enter runaway if absorbed solar flux exceeded that value. Wordsworth (2015, Astrobiology) likewise reported the Simpson–Nakajima limit at~ 280 W/m^2 . One-dimensional studies show that above Ts ≈ 350 K (≈ 77 ^{0}C) OLR approaches the asymptotic limit . Recent 3D simulations (Wolf & Toon 2015, J. Geophys. Res.) found that with +21 % insolation, global mean temperature exceeds 360 K ($\tilde{8}$7 ^{0}C) as the runaway transition is approached.
Connection to +70 ^{0}C warming: These studies consistently indicate that runaway or moist greenhouse states require warming of several tens of degrees Celsius relative to today. For instance, Goldblatt & Watson (2012) found that at Ts ≈ 340 K (≈ 67 ^{0}C) Earth's atmosphere enters a moist greenhouse regime . Wolf & Toon (2015) found runaway onset near Ts ≈ 360 K ($\tilde{+}$75 ^{0}C). Overall, analyses indicate that the radiative limit corresponds to global warming on the order of +60–+80 ^{0}C above preindustrial conditions. The critical OLR ($\tilde{2}$80–282 W/m^2) coincides with surface temperatures of several hundred Kelvin, i.e.~ +70 ^{0}C higher than today's mean ($\tilde{2}$88 K). References: Foundational and modern studies on the runaway greenhouse include Kasting (1984 , 1988), Nakajima et al. (1992), Goldblatt et al. (2013) , Wordsworth (2015) , and Wolf & Toon (2015) . Together, they confirm that Earth's radiative li mit occurs only at much higher surface temperatures than today (warming of~ +60 – +80 ^{0}C), at a critical OLR of~ 280–282 W/m^2.

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