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Communities and local sustainable development

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MODERN TRANSPORTATION AND PHOTOVOLTAIC ENERGY FOR URBAN ECOTOURISM

Raffaella AVERSA
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Abstract

This study proposes an innovative integrated transportation/photovoltaic energy system that will enable the Pompeii Municipality to develop a set of urban ecotourism policies and instruments for the preparation and adoption of an environmental sustainable mobility strategy to be applied in their future municipality urban plan. The innovative character of the study resides in two principal aspects: the technologies applied, namely, the use of thin film photovoltaic (hereafter PV) panels (copper-indium-gallium-(di)selenide cells) on a flexible support, and the way these technologies are applied. A combined energy/mobility approach based on 'Zero km and zero emission energy production for zero emission electric transportation strategy' to be implemented in the Public Urban Plan (Piano Urbanistico Comunale) of the town of Pompeii is presented. According to the technology to be adopted (thin PV film on flexible supports integrated in the parking shelters roofs), to the foreseen PV plant of 700 sqm parking lots, and to an innovative multifunctional design approach (bio-mimicking sun track roof), an improved yearly power production of 100.0 MWh is foreseen with a 20-25% increase of power production with respect to standard fixed PV panels of the same type.

Keywords*:* social sciences, sustainable tourism, modern transportation, flexible photovoltaic energy, urban plan.

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1. Introduction

Tourism is changing rapidly as nature, heritage and recreational destinations become more important and easy to reach, and, therefore, it should be forced to meet tougher environmental requirements, especially in urban environment where its anthropic impact overlaps local criticism.

The balance between economic growth, social wellbeing and environmental protection is a growing concern of industrial research development.

This will be at the base of the future development of our technosphere, the virtual space where techno diversity interacts with the biosphere (Barrett and Odum, 2000; Iqbal, 2016; Sepúlveda, 2015; Pisello *et al.*, 2016).

Environmental challenges, such as climate change and scarcity of resources, constrain and open opportunities for new technological developments in the same time, including in the composite materials field (Apicella *et al.*, 2010; Aversa *et al.*, 2017a-c; Colvin, 2004; de Silva *et al.*, 2009; Kaebernick *et al.*, 2002; Mirsayar *et al.*, 2017; Petrescu *et al.*, 2017a-e). Sustainability is a serious issue in the long run, for the future of the world, but it is particularly critical in Europe due to their rapid and uncontrolled industrial growth in an environment that should preserve its cultural history.

The rational use of energy by adopting greener sources and by controlling production will improve our valuesphere (the scientific environment accounting for ecological issues while protecting occupation and welfare).

Touristic cities' authorities are asked to face a double challenge: they have to be able to respond to the expectations and the needs of the growing numbers of tourists, while ensuring that tourism is developed and managed in such a way that it benefits the resident population, does not contribute to the deterioration of the urban environment, but rather to its enhancement, and does not become a financial burden (Malkin, 1999).

Campania is a region of Italy with a strong tourist vocation: it is the territory that attracts the majority of tourism in Southern Italy especially for the presence of the touristic highly attractive poles: Capri, Ischia, Sorrento, Amalfi and Pompeii. Such world cultural heritage has to share the territory with a highly inhabited town, and an area of intense tourism and flower farming. As noted by the World Bank (1999), 'Cultural tourism can encourage the revival of traditions and the restoration of sites and monuments. But unbridled tourism can have the opposite effect'.

2. Methods

2.1. Environmental problem targeted

2.1.1. Tourism cities anthropic impact

The most recent trends and forecasting studies by the World Tourism Organization (2017) indicate that cities will continue, especially in the areas of great cultural interest such is Pompeii, to be in high demand by tourists of all sorts (cultural and religious). In fact, the modern town has grown on the ancient Roman ruins (Figure 1).

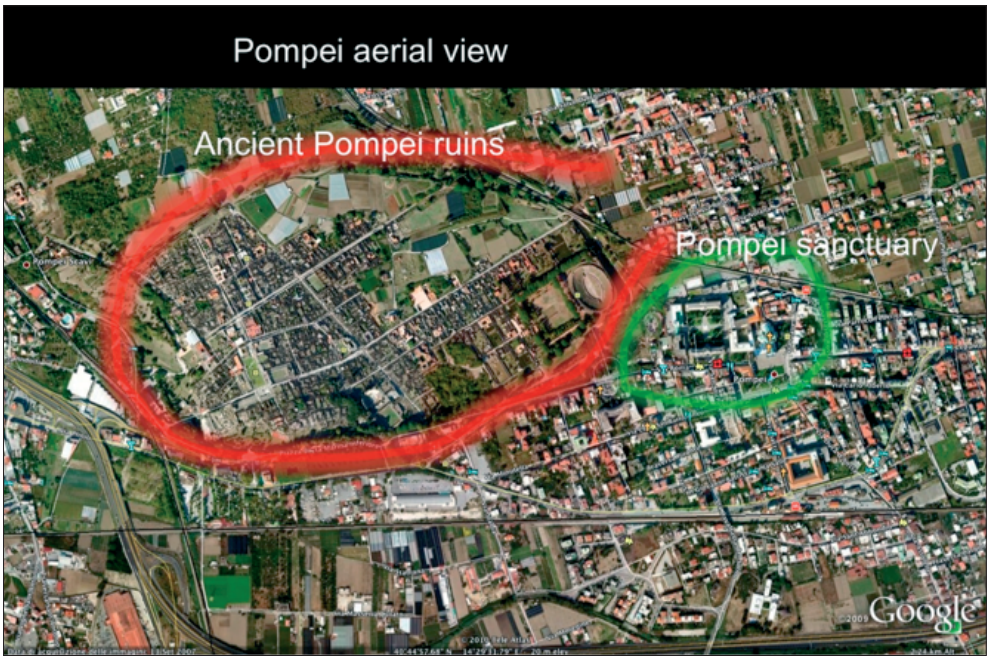

Figure 1: Map of the POMPEII downtown, ancient town excavation and Sanctuary showing the areas of interest for the study

Source: Aerial view from Google Earth, 2010

If we consider archaeological cities, such is the town of Pompeii, we note that there is a lot of pressure in terms of time and space caused by a concentrated tourist influx, which adds to other factors of anthropic origin but of a different nature, such as the rapid urban growth of the town and the presence of the Catholic Sanctuary of the Madonna (Blessed Virgin Mary). The presence of the Sanctuary attracts an even greater and continuous flux of pilgrims: numerically, it is about 7 million people yearly (2.5 million people for the excavations, and 4.5 million for the Sanctuary; see Figure 2).

Such huge numbers of incoming people (meanly 20,000 a day over a population of 25,000 people) concentrated in the same area (the ruins entrance and the Sanctuary are in close proximity) creates an additional intense and significant traffic of buses (about 400 daily) and cars (100 daily) in a range of 3 km (the distance from the highway to the center of the town, where the excavations and Sanctuary are located) that is equivalent to a total of 1,000,000 km of bus journeys (based on a medium sized diesel bus).

Noise and gaseous pollutants emissions are a serious concern for the livability and fruition of the town (European Commission, 1996, 2001, 2005): collectively these vehicles emit in a year 120 tonnes of CO_2, 1.4 tonnes of CO, 0.4 tonnes of Nitrogen Oxides (NO_x) and 0.4 tonnes of Volatile Organic Compounds (VOCs), with a noise pollution that has been measured in a preliminary soundscape study carried out by the University of Campania for the external rush hours road traffic of 60-70 dB (A) centered on a

Figure 2: Anthropic impact of tourists and pilgrims on the new town of Pompeii

Source: Author Apicella's personal pictures, 2014

frequency spectrum of 2.4-2.8 (log Hz), according to the European Commission Green Paper on Future Noise Policy (European Commission, 2004) and Directive 2002/49/EC.

The problems associated with the daily handling of this growing mass of tourists (7 million a year, 20,000 a day) will have to be more systematically tackled by all parties concerned with a better management of urban areas through integrated environmental management at the local level. At the present time, a rational plan to reduce the anthropic impact of this intense form of city tourism does not exist at local level.

Our project proposes an innovative prototype integrated transportation/energy system that will enable the Pompeii Municipality to develop, from the results of the demonstration activities of the study, a set of urban ecotourism policies and instruments for the preparation and adoption of more environmentally sustainable mobility strategies to be applied in the future PUC (Municipality Urban Plan).

A map of the Pompeii town with indication of the principal areas of touristic interest (ancient town excavations and Sanctuary), and the nodes of the proposed study are reported in Figures 1 and 4.

2.1.2. Combined energy/transportation strategies

The innovative character of our approach resides in two principal aspects:

– the technologies applied: the use of thin film flexible photovoltaic panels (copper-indium-gallium-(di)selenide cells); and

– the way these technologies are applied: the combined energy/mobility approach 'Zero km and zero emission energy production for zero emission electric transportation strategy' to be adopted and implemented in the Public Urban Plan (Piano Urbanistico Comunale) of the town of Pompeii.

2.2. Innovative urban ecotourism policies

A more sustainable tourism can be achieved by the implementation of existing EU environmental policies for urban eco-tourism in highly inhabited areas. The 'Zero km and zero emission energy production for zero emission electric transportation strategy' derives from the above mentioned energetic and environmental considerations and is to be adopted in a context where sustainable development needs specific and targeted policies to be developed and adopted by the Pompeii Municipality.

The proposed demonstrative integrated transport and energy model for an urban green management is based on the following points:

– 'Pompeii, The Clean Energy Town';
– 'Zero Emission – Zero Km Energy' (solar electric energy local production); and
– 'Zero Emission Transportation System' (electric minibus city mobility plan).

2.3. Environmental benefits of an integrated clean energy/transportation strategy

The environmental benefits to be achieved with the future application in the Pompeii urban planning of the policies developed in the framework of this project implementation will attain abatements of the above-mentioned values of pollutants and noise (busses will be completely banned from the town traffic through the activation of external BIPV – Building Integrated Photo Voltaic – parking and electric shuttles).

A similar touristic anthropic load is occurring in the Chinese touristic site of Xi'An, and in this case the electrically based transportation solution has been adopted (Figure 3).

Ordinary energy consumption requirements for parking areas (no night lighting is considered since tourism in this town is concentrated in the daylight hours), for air conditioning and energy consumption of bus shuttles have been evaluated in terms of TPE (Tonne Petroleum Equivalent), while considering conventional energy sources, and then compared to our foreseen PV energy production.

Considering that, in the proposed mobility plan the use of shuttles from the parking to the areas of interest (excavation and Sanctuary) is expected to run at least 25 round trips (4 km) a day for each minibus for a total of 32,000 km in a year (320 operating days) leading to a consumption of 2,500/3,750 liters of fuel. In terms of TPE, this corresponds to a consumption of about 2.8/4.0, and an energy consumption requirement of 32/46 MWh.

An equivalent electric minibus can operate at 10 kWh for 100 km: over the same distance of 32,000 km a year, the energy consumption requirement is of 4.5 MWh that theoretically (considering the above mentioned PV power potential of 700 sqm PV roofs of 100 MWh) permits the use of 20 electric minibuses (7,500-10,000 passengers).

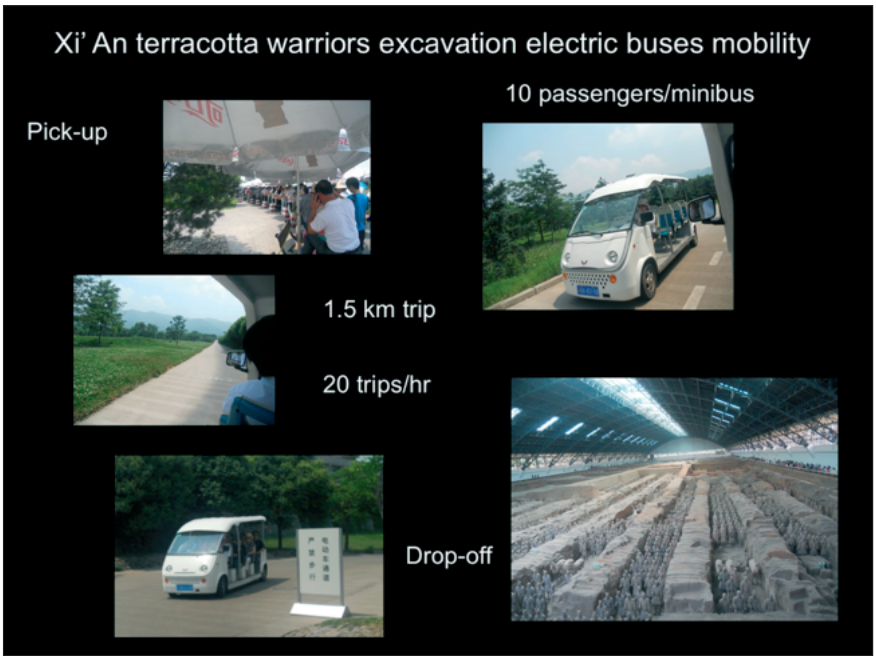

Figure 3: Electric transportation system in the terracotta warriors archeological side of Xi'An, China

Source: Author Apicella's personal pictures, 2014

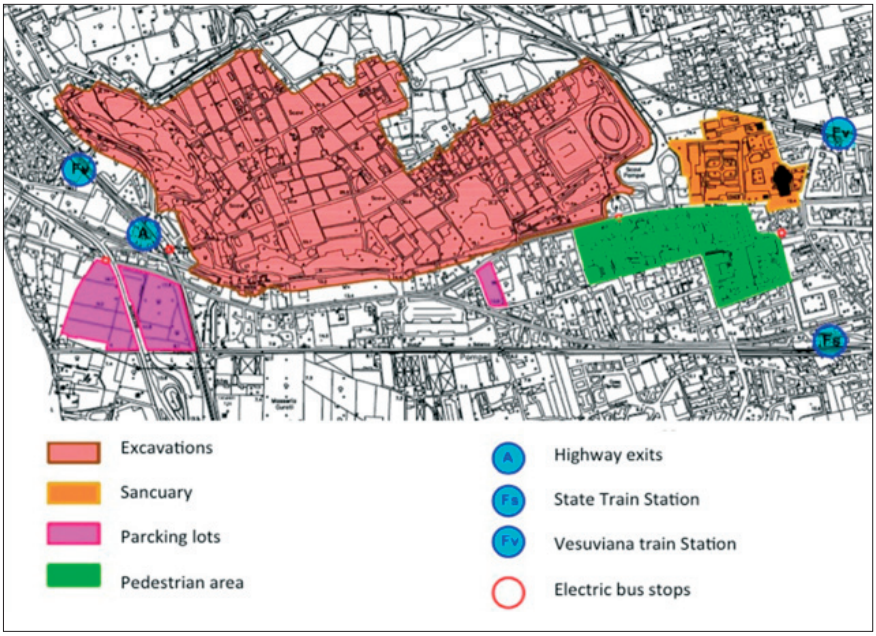

Figure 4: Map of the Pompeii downtown, ancient town excavation and Sanctuary showing the areas of interest for the study

Source: Pompeii Municipality, 2011

Figure 4 reports a map of the Pompeii Municipality indicating the more relevant areas involved in the new mobility study:

- the potential parking areas locations (violet on the map) where the PV parking shelter roofing could be implemented;
- electric bus trip (grey in the map) from parking lots to the areas of interest;
- pedestrian area (green) that is expected to be closed for private car traffic in order to ensure the project implementation, and the noise and pollution claimed levels of maintenance;
- the historical ancient town (excavations, light red);
- the Sanctuary and related structures (orange);
- the highway exits (A in a light blue circle), the state railway station (Fs in a light blue circle);
- the private 'circumvesuviana' railway station (*Fv* in a light blue circle);
- the foreseen electric shuttles stops (red circle); and
- the public greenhouse (municipality) involved in the project (green circle) have been marked on this first map.

2.4. Cost/benefit analysis and sustainable development in high historical and cultural heritage cities

Photovoltaic systems per se are not a good choice of a 'cost-benefit' analysis in terms of tonne of $eqCO_2$ reduction. However, this is not the exclusive aim that this study has been based on. Even if significant results on tonne of $eqCO_2$ reduction can be attained by the initiative (it is expected to significantly reduce the heavy tourist buses traffic in the area of excavations and Sanctuary), this study evaluates and presents new strategies specifically addressed to contribute to the implementation, updating and development of community environmental policy and legislation that include the integration of the environment into other policies, thereby contributing to sustainable development in areas of intense tourism. Moreover, sustainable development in areas of high historical and cultural heritage values necessitates a specific and targeted approach going well beyond ordinary indicators. The area of the study has been inscribed by UNESCO as a world heritage with the following justification: '(…) the impressive remains of the towns of Pompeii and Herculaneum and their associated villas, buried by the eruption of Vesuvius in AD 79, provide a complete and vivid picture of society and daily life at a specific moment in the past that is without parallel anywhere in the world' (European Commission, 2012).

Such world cultural heritage has to share the territory with a highly inhabited town, and an area of intense tourism and flower farming. The proposed initiative is balancing environmental, cultural and socio-economic needs in order to achieve a set of new policies to be adopted by the municipality in its Urban Plan in order to improve the inhabitants' quality of life and the quality of tourists' services, while preserving this unique historical treasure from degradation.

Our project adopted the strategies for sustainable development underlined in the Presidency conclusion document of the Göteborg European Council (European Council, 2001):

- Dealing with economic, social and environmental policies in a mutually reinforcing way to promote sustainable development (point 19);
- Adding a third, environmental dimension to the Lisbon strategy, and establishing a new approach to policy making (point 20); and
- Developing a broader use of new environmentally friendly technologies in sectors such as energy and transportation (point 21).

The proposed study refers to the 'Clean Air for Europe' programme (European Commission, 2001) and the European Community INSPIRE initiative (Directive 2007/2/EC) aimed at reducing pollution by 2020. The reduction of atmospheric pollution, such as that caused by transportation and fuel based energy generation, also implies a reduction of noise pollution.

2.5. Innovative sustainable technical solutions

The innovative character is based on these principal aspects:

- the technology to be adopted (thin PV film on flexible supports integrated in parking shelters flexible roofs);
- the foreseen mean PV plant of 700 sqm; and
- an innovative multifunctional design approach (flexible tracking roof) (Figure 5).

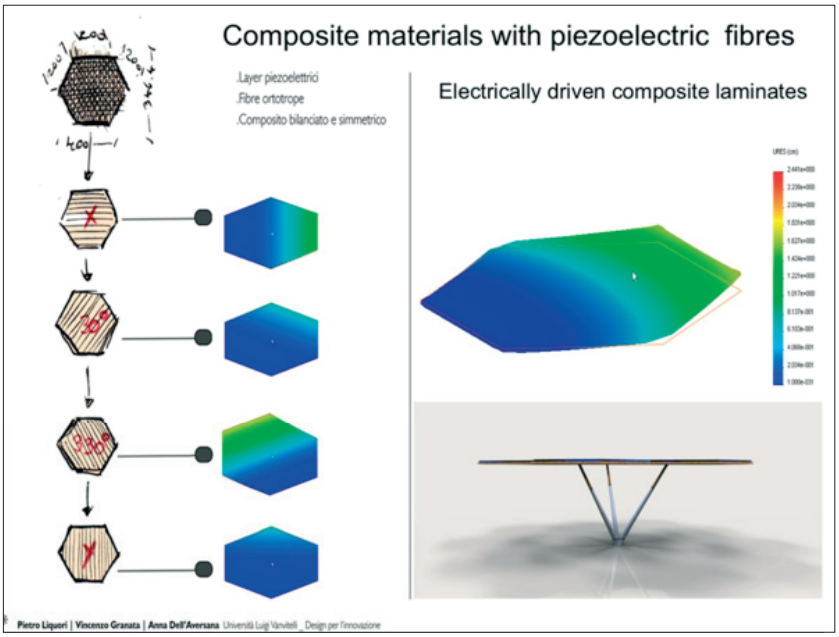

Figure 5: Self sun-tracking roof system based of piezoeletric or shape memory alloys composit PV supports

Source: Authors' own contribution

A self sun-tracking system based on the use of composite laminates containing properly oriented glass fibers and piezoelectric fibers in its different laminae is proposed. Such laminate, when electrically stimulated, could warp according to the intensity and position of the stimulated lamina. This electrical stimulation can be automatically driven by the position of the sun hitting sensors in different areas of the PV roof. Figure 5 shows the functional principle of the proposed system.

An improved yearly power production of 100.0 MWh is foreseen with a 20-25% increase of power production with respect to standard fixed PV panels of the same type.

2.6. Thin film flexible photovoltaic modules

Tensile Photovoltaic structures are lightweight, modular systems that provide shade while producing solar power. A thin film PV technology using Copper Indium Gallium di-Selenide (GIGS) has been chosen as alternative to the traditional PV based on crystalline silicon rigid modules (Solar Energy Industries Association, 2015). Figure 6 below details the efficiency evolution of PV from 1975 to 2015.

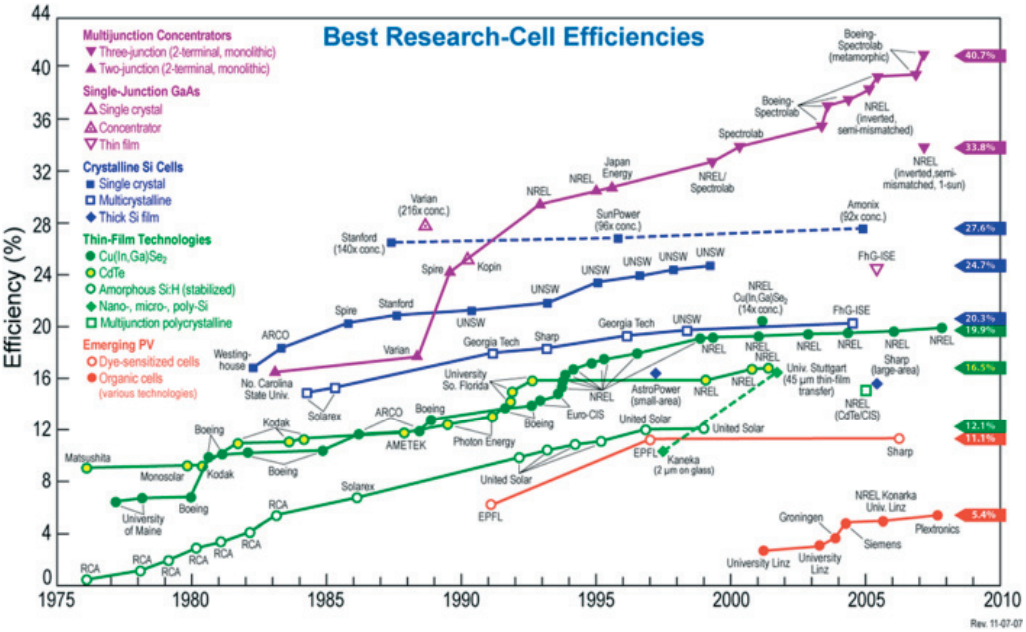

Figure 6: Efficiency evolution of PV from 1975 to 2015. Maximum development of the thin film PV is forecast by National Renewable Energy Laboratory for years 2015-2020

Source: National Renewable Energy Laboratory (2015)

This choice has been driven by the fact that this is a promising technology that is rapidly growing and that could supply interesting commercial products that can be applied on flexible support and used in new design solar tracking modules (of the type presented here). Efficiency for this type of cell could reach 20% in the next few

years. However, the use of lower cost technologies of deposition is able to guarantee 10/15% efficiency at lower plant costs. National Renewable Energy Laboratory forecasts a maximum development of these technologies for the years 2015-2020 (NREL 2015).

The use of such thin films on flexible polymeric substrates permits the application of an innovative sun tracking system (based on biomimetic self sun-tracking system) production of the plant. For such a system a conservative efficiency of 10% has been considered.

The use of a piezoelectric smart system allows warping and redirecting the composite laminate substrate in the direction of the sun (Figure 7). This occurrence increases the amount of sun-light that is captured by the PV flexible module.

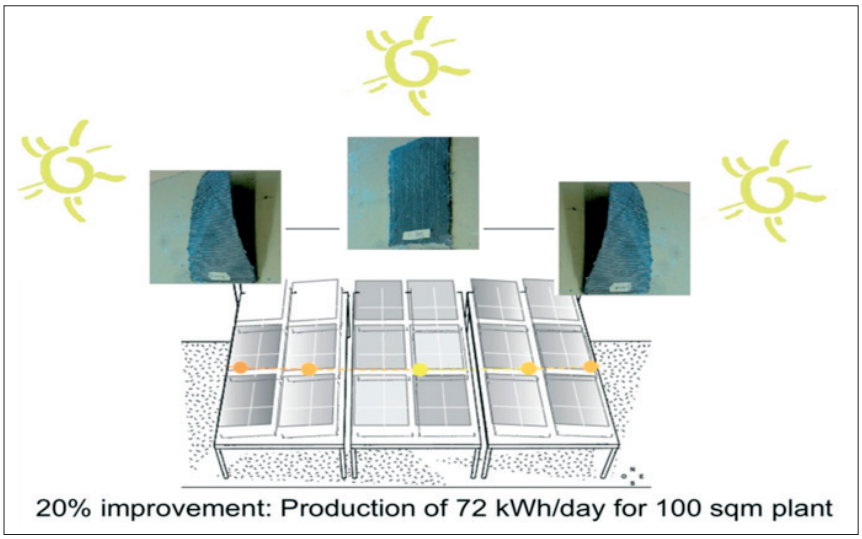

Figure 7: Self sun-tracking roof system based of piezoeletric or shape memory alloys composit PV supports

Source: Authors' own contribution

A 100 square meters array of 140 modules has the following foreseen year power production:

- traditional – 12 MWh; and
- bio-inspired sun tracking system – 15 MWh.

A 700 sqm plant has been considered in our study with a potential 100MWh power production.

The energy competitive advantages of the proposed coupled PV energy production and electric transportation new approach arise from different technical considerations:

- the use of electric transportation that needs (over the year for each vehicle) 4.8 MWh vs. 32/46 MWh needed by traditional shuttle buses (internal combustion engines);

– the use in the electric transportation of locally generated electricity from PV instead of electricity from traditional sources (which strongly depend on thermoelectric). In fact, considering real process efficiency in conventional thermoelectric power plants, the actual TPE consumption for traditional energy sources should be at least doubled; and
– the use of electric transportation from peripheral parking lots and the central historical area (centrum of the town) reduces the heavy noise and gas pollution by tourist busses.

3. Results and discussion

New approaches to sustainable development and economy based on new materials and technologies have been proposed by our research group (Apicella *et al.*, 2015; Annunziata *et al.*, 2006; Aversa *et al.*, 2016a, 2016b, 2016c, 2016d; Petrescu *et al.*, 2016a, 2016b; Petrescu and Calautit, 2016).

Campania is a region of Italy with a strong tourist vocation: it is the territory that attracts the majority of tourism in Southern Italy especially for the presence of touristic highly attractive poles: Capri, Ischia, Sorrento, Amalfi and Pompeii.

Tourism's economic impact is significant and still growing. Tourism can make an important contribution to economic development; however it can generate a variety of other impacts, both positive and negative. It can help keep traditions alive and finance the protection of the cultural and natural heritage, as well as increase visitors' appreciation of that heritage.

Conversely, tourism can damage heritage when it is not managed well. Thus, there is a tension between tourism and cultural and natural heritage preservation.

The proposed initiative is balancing environmental, cultural and socio-economic needs in order to achieve a set of new policies to be adopted by municipalities in their urban plans in order to improve the inhabitants' quality of life and the quality of tourists' services, for preserving this unique historical treasure from degradation.

Similar initiatives could have positive impact also in other large cities in order to improve the quality of transportation and energy efficiency, especially in the downtown areas where traffic gas and noise pollution are important issues. The adoption of such strategies can drastically reduce traffic while improving the quality of air and contribute to a sound environment.

However, such new strategies are not only addressed to achieve environmental benefits, but they can also result in local economic benefits. In fact, high innovative electric transportation could significantly enhance certain economies, at least in Europe and the USA, especially when these economies hold high technology based industries, which will be beneficial for research and development, and direct support for companies' expansion (i.e., factories financing).

The use of innovative solutions (Figure 8), such as flexible and self sun-tracking systems driven by piezoelectric or shape memory alloy smart materials (Aversa *et al.*, 2016b), structural colors (Aversa *et al.*, 2016c), developed in the framework of an evo-

lutionary design approach (Aversa *et al.*, 2016a), could lead to more sustainable and environmental friendly solutions.

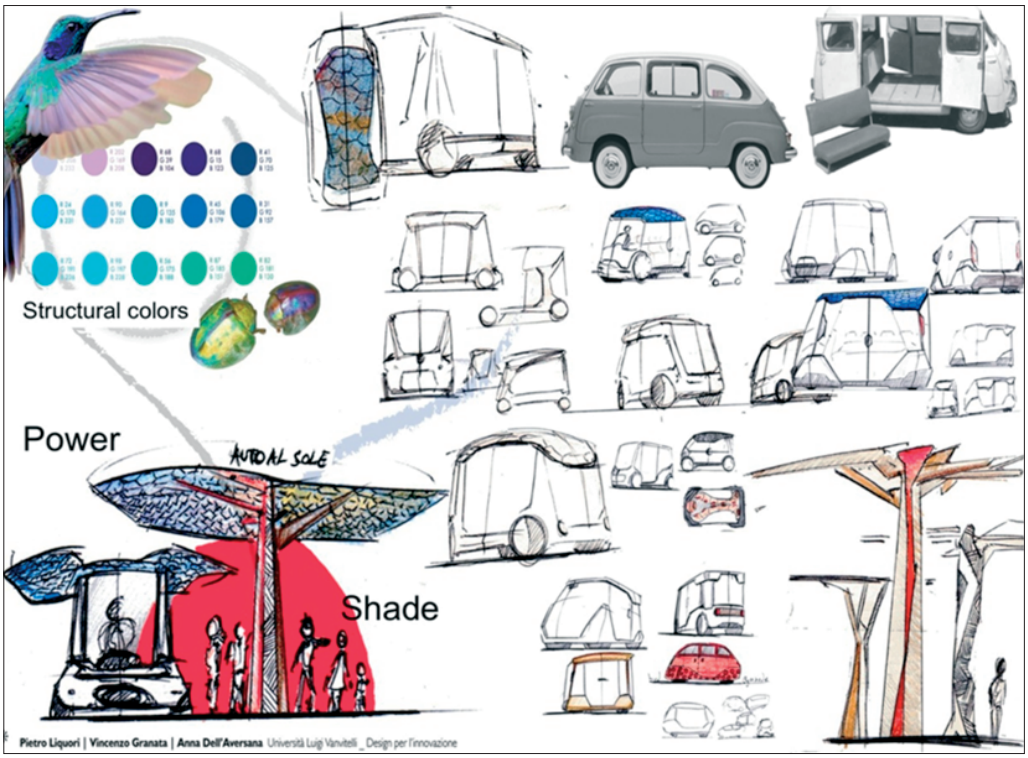

Figure 8: Structural colors, electric minibus transportation and PV shelters

Source: Authors' own contribution

If we consider archaeological cities, such as the town of Pompeii (the modern town grown on the ancient Roman ruins as reported in Figure 1), there is a lot of pressure in terms of time and space caused by a concentrated tourist influx, added to other factors of anthropic origin but of a different nature such as the rapid urban growth of the town and the presence of the Catholic Sanctuary of the Madonna (Blessed Virgin Mary) that attract an even greater and continuous flux of pilgrims.

4. Conclusions

A combination of energy and mobility strategies based on 'Zero km and zero emission energy production for zero emission electric transportation strategy' could be introduced in the Public Urban Plan (Piano Urbanistico Comunale) of the town of Pompeii.

The environmental benefits to be achieved with the future application in the Pompeii urban planning of the policies developed in the framework of this proposed approach could attain high enhancements of pollutants and noise abatements (busses

will be completely banned from the town traffic through activation of external BIPV – Building Integrated Photo Voltaic – parking and electric shuttles).

The environmental benefits that are strictly related to the project implementation are limited (but, anyway, significant) to the partial closure of the centrum to busses that will reduce 1/6 of the gaseous emissions: namely, 20 tonnes of CO2, 0.2 tonnes of CO, 80 kg of Nitrogen Oxides (NOx), and 80 kg of VOCs. Due to the closure of the contemporary Pompei Centrum (which corresponds to the Sanctuary and main excavation entrance) to heavy and private vehicles traffic, it is expected to lower the noise pollution.

This study proposes an innovative integrated transportation/photovoltaic energy system that will enable the Pompeii Municipality to develop a set of urban ecotourism policies and instruments for the preparation and adoption of an environmentally sustainable mobility strategy to be applied in their future municipality urban plan.

New developments in electric transportation are attracting great public interest and they are fields with great dynamism driving continuous changes in national policies. Germany, China, and South Korea are leaders in innovation followed by France, United Kingdom, United States, and Austria, while policies stimulating innovation, such as research and development and industrial pilot projects, are not yet sufficiently adopted in the Netherlands, Belgium, Denmark, Norway, Portugal, Italy, and Spain (Weeda *et al.,* 2012, pp. 14-16).

The innovative technological character of the proposed study resides in two principal aspects: the technologies applied, namely, the use of thin film photovoltaic panels (copper-indium-gallium-(di)selenide cells) on a flexible support, and the way these technologies are applied.

According to the technology to be adopted (thin PV film on flexible supports integrated in the parking shelters roofs), to the foreseen PV plant of 700 sqm parking lots, and to an innovative multifunctional design approach (bio-mimicking sun track roof), an improved yearly power production of 100.0 MWh is foreseen with a 20-25% increase of power production with respect to standard fixed PV panels of the same type.

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