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APPLYING DYNAMIC PERFORMANCE MANAGEMENT TO THE PHOTOVOLTAIC SECTOR:
THE MUNICIPALITY OF PALERMO CASE STUDY

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PREFACE

Communities worldwide demand for energy provision to meet basic human needs, to ensure access to public services, and to serve production processes.

In order to fulfil such energy needs, the use of fossil fuels (coal, oil, and natural gas) has increased worldwide to dominate energy supply, especially since the dawn of the industrial age.

As a result, carbon dioxide (CO_2) concentrations – released into the atmosphere during the combustion (burning) of fossil fuels – have risen exponentially thus contributing to the increase of land surface temperature (Krauter, 2006).

Such a phenomenon, commonly known as "*global warming*", may turn into disastrous consequences (*e.g.*, sea level rise, spread of diseases, and impacts on agriculture) thus becoming life-threatening for humanity.

To limit such a phenomenon, anthropogenic CO_2 emissions should be reduced through energy efficiency measures, energy consumption reductions, and the adoption of accessible and environmentally friendly energy sources (Pode & Diouf, 2011).

Renewable energy sources (RES_s) – such as solar, wind, hydropower, ocean, and geothermal energy – can provide a viable alternative to meet energy requirements in a sustainable way.

Over the last decade, among the various technologies based on RES_s, Italy recorded a remarkable growth in solar photovoltaic (PV) systems installed[1] (GSE, 2013), thanks to the support of a government incentive mechanism called "feed-in

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[1] PV is a technology that converts sunlight into direct current electricity.

tariff" (FIT), which became operative in 2005 and definitively ceased to be applied in 2013.

Indeed, such a mechanism – based on a system of tariffs determined by public authorities and guaranteed for a specific time interval – aimed at boosting PV investments by both private and public sectors.

Notably, public sector organizations are expected to take an active role in leading a change based on the use of sustainable energy in order to provide a good example to the whole community towards the reduction of CO_2 emissions and, thereby, promoting awareness and social acceptance of renewable sources.

In addition, their commitment is strongly required in order to achieve (or even exceed) EU emission targets through, for instance, the development of action plans embodying energy efficiency measures such as the adoption and use of solar PV systems.

Nevertheless, over the last few years, the PV power installed in the Italian public sector has started slowing down, thus determining changes in clean energy production from PVs, as well.

In order to better support the design of policies and strategies for the sustainable development in terms of clean energy, one possible way is the adoption of a "Dynamic Performance Management" (DPM) approach, which is a combination of the traditional Performance Management (PM) systems with the System Dynamics (SD) methodology.

Indeed, such an approach may allow overcoming the limitations of the traditional PM systems, which so far result in formal duties to be fulfilled, rather than means through which promote long-term plans aimed at promoting clean energy.

Based on the above premises, this research study aims at enhancing the design, adoption, and evaluation of public policies for PVs in order to foster clean energy production in the Italian context.

To this end, the thesis is organized in four chapters.

Chapter 1 is intended as an introduction to the research study by following a "*funnelling process*", which moves from a general overview to the core of the research design. Thus, the chapter presents the research background and defines the objective and boundaries of research in order to narrow the scope of the study.

Finally, the formulation of research questions and an outline of the methodological approaches adopted for carrying out this research study will be illustrated.

Chapter 2 introduces the solar PV technology – from a technical viewpoint – and discusses the role Italian public organizations can play in furthering energy efficiency improvements by means of PVs. Major bureaucratic, social, and financial issues that might affect the adoption of PV systems are also presented. Finally, the recent trend of PV power installed in the public sector is provided.

Chapter 3 emphasizes the need for combining SD methodology with the traditional PM systems *i.e*. the DPM approach. The contribution of such an approach to better support public decision-makers' strategic learning processes is framed by envisaging two levels of analysis *i.e*. the institutional and inter-institutional ones with applications to the PV sector.

In Chapter 4 the DPM approach is applied to a case study based on the PV sector of the Municipality of Palermo (Italy) in order to enhance public decision-makers' strategic learning processes with a view to fostering clean energy production. To this end, both the qualitative mapping approach (Causal Loop Diagram) and the quantitative simulation modeling (Stock & Flow model) are adopted. The chapter ends with a discussion of possible scenarios and related simulation results.

Conclusions, limitations and recommendations for further research follow. Lastly, appendices provide supplementary information to the model built for Palermo Municipality by recalling both the model equations and the model structure.

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LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
AC	Alternating Current
ARIS	Agenzia di Ricerche Informazione e Società
Avg	Average
BANANA	Build Absolutely Nothing Anywhere Near Anyone
BEI	Baseline Emission Inventory
B loop	Balancing loop
BIPV	Building-Integrated Photovoltaic
BOS	Balance Of System
CIGS	Copper Indium Gallium Diselenide
CLD	Causal Loop Diagram
CPV	Concentrated Photovoltaic
DC	Direct Current
DPM	Dynamic Performance Management
ECoC	European Capital of Culture
ENEA	Agenzia Nazionale per le nuove Tecnologie, l’energia e lo sviluppo economico sostenibile
ESCo	Energy Service Company
EVA	Ethylene Vinyl Acetate
FIT	Feed In Tariff
GHG	Greenhouse Gas
GISS	Goddard Institute for Space Studies
GSE	Gestore dei Servizi Energetici

HR	Human Resources
IBIPV	Innovative-Building-Integrated Photovoltaic
IBPV	In-Building Photovoltaic
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JUG	Joined-up Government
LULU	Locally Unwanted Land Uses
MedClima	Climate Alliance for Mediterranean Cities
MEP	Municipal Energy Plan
MD	Ministerial Decree
MIT	Massachusetts Institute of Technology
MPPT	Maximum Power Point Tracking
NASA	National Aeronautics and Space Administration
NIABY	Not In Any Backyard
NIMBY	Not In My Backyard
NIMTO	Not In My Term of Office
NIPV	Not-Integrated-in-building Photovoltaic
NOP	National Operational Programme
NOOS	Not On Our Street
NOTPE	Not On The Planet Earth
NREAP	National Renewable Energy Action Plan
OECD	Organization for Economic Co-operation and Development
PPP	Public-Private Partnership

OPV	Other Photovoltaic
P&C	Planning & Control
PIs	Performance Indicators
PIPV	Partially-Integrated-in-building Photovoltaic
PV	Photovoltaic
PM	Performance Management
R&D	Research & Development
$\text{RES}_{(s)}$	Renewable Energy $\text{Source}_{(s)}$
RES-E	Renewable Energy Source for Electricity
R loop	Reinforcing loop
SD	System Dynamics
SEAP	Sustainable Energy Action Plan
S&F	Stock & Flow
SPM	Strategic Performance Management
TPF	Third-Party Financing
UNEP	United Nations Environment Programme
WCED	World Commission on Environment and Development
WMO	World Meteorological Organization
ZEN	Zero Emission Neighbourhoods

LIST OF SYMBOLS

SYMBOL	MEANING
A-Si	Amorphous Silicon
CdTe	Cadmium Telluride
CFCs	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon dioxide
C-Si	Crystalline Silicon
Ec	Conduction Energy Edge
Eg	Band Energy Gap
Ev	Valence Energy Edge
H_2O	Water vapour
Kw	Kilowatt
Kwh	Kilowatt-hour
Kwp	Kilowatt peak
MW	Megawatt
MWp	Megawatt-peak
N_2O	Nitrous oxide
O_3	Ozone

CHAPTER 1

INTRODUCTION TO THE RESEARCH STUDY

This chapter aims at introducing the research study by providing a comprehensive background beforehand to allow one a better understanding of the context in which the research is positioned. Based on such a background, the objective and boundaries of research are presented with the intent to narrow the scope and, then, the focus of this research study. The formulation of research questions – indicating what the research is specifically going to look at – follows. Lastly, the chapter sets out the methodological approaches adopted to fulfil the overall research objective.

1.1. RESEARCH BACKGROUND.

Over the past centuries, according to a research study carried out at the NASA Goddard Institute for Space Studies (GISS), the global average temperature has recorded an increase by around 0.8° Celsius equivalent to almost 1.4° Fahrenheit (Hansen *et al.*, 2010).

Such a continuous rising in the average temperature of Earth is commonly known as "*global warming*"[2] and, today, it is considered one of the greatest threats to the current and future generations because of its wide range of potential aftermaths *e.g.* sea level rise, spread of diseases, and impacts on agriculture[3] (Smith *et al.*, 2001; IPCC, 2013).

Variations in land surface temperature are due to as many alterations in Earth's energy balance[4] which, in turn, might be unleashed by both natural (*e.g.,* volcanic eruptions, and solar radiation) and anthropogenic *i.e.* human-induced processes.

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[2] The terms "global warming" and "climate change" are often used interchangeably in normal daily communications although they refer to different concepts. Indeed, the second one, as the name suggests, refers to a long-term change in the Earth's climate as result of the rising average temperature of the Earth. For example, changes in precipitation patterns, increased prevalence of droughts, and heat waves (NASA, *What is in a name?, http://pmm.nasa.gov/education/articles/whats-name-global-warming-vs-climate-change*).

[3] Note that measurement of temperature and, then, global warming varies depending on time frame.

[4] Actually, two types of radiative forcings – acting in different ways – drive alterations in Earth's energy balance: positive radiative forcings – which cause an increase in the energy of Earth's atmosphere thus leading to a warming of the system – and negative radiative forcings that push the system towards cooler surface temperatures.

In its working group contribution to the fifth Assessment Report (5AR) published in 2013 and addressed to policy-makers, the Intergovernmental Panel on Climate Change (IPCC)[5] came to the following conclusion: "*it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century*" (Stocker *et al*., 2013: 15).

Such a conclusion has found empirical evidences in the increasing anthropogenic greenhouse gas (GHG)[6] concentrations in the atmosphere, primarily carbon dioxide (CO_2) that has risen to unprecedented levels since pre-industrial times[7].

Fossil fuels[8] – mainly oil, coal, and natural gas – might be acknowledged as the major determinants of massive CO_2 concentrations present in the atmosphere as a result of human activities.

The wide-scale use of fossil fuels across the world is associated with their aptitude to generate energy through a chemical reaction known as "combustion or burning" which takes place – through consecutive steps – in industrial facilities called power stations.

At the end of such a process, the generated energy is ready to be exploited for serving multiple purposes, such as public services, transportation, industrial and commercial productions and last, but not least, for meeting households' electricity energy needs.

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[5] In 1988, the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) established it. Its major mission is to provide a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts.

[6] A greenhouse gas is any gaseous compound in the atmosphere that absorbs infrared radiation, thereby trapping and holding heat in the atmosphere. Such a natural process is known as "greenhouse effect". However, an excessive concentration level of such gases in the atmosphere would result in an enhanced greenhouse effect, thus leading to the global warming effect.
The most abundant greenhouse gases in Earth's atmosphere are the following: water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and Chlorofluorocarbons (CFCs).

[7] In particular, the Pre-1750 tropospheric concentration of CO_2 were around 280,000 parts per billion (ppb) while the recent levels of concentration are around 388,500 ppb (Blasing & Smith, 2011).

[8] Originally, fossil fuels were formed millions of years ago during a time phase of the Palaeozoic Era known as "*Carboniferous Period*" as they embodied high percentages of carbon.

Beside some financial and non-financial advantages[9] that might make convenient opting for fossil fuels as energy sources, there are also some substantial drawbacks making them "*non-sustainable energy sources*".

First, it is extremely likely that, in the near future, the availability of fossil fuels might be highly undermined by the depletion of their existing natural reserves since there is a lack of equilibrium between the very fast rate at which they are currently exploited and the exceedingly slow rate at which they will be replenished in the future[10].

The second most important disadvantage is directly linked to the chemical reaction (*alias* combustion) of fossil fuels since, during such a process, they give large amounts of CO_2 molecules off in the atmosphere thus leading to an intensification of the natural greenhouse effect and, then, to the afore-mentioned global warming phenomenon.

Throughout the years, policy-makers – at local, national, and international levels – have sought to lessen the likelihood that potential adverse risks[11] might occur in upcoming years by embedding adaptive[12] and mitigation actions in their strategic plans (Field *et al*., 2014- IPCC 2014).

Among the possible avenues for limiting CO_2 emissions[13] while still providing the desired energy services, renewable energy sources (RES_s) might play a remarkable role since they would allow meeting energy demand into a more sustainable way (Moomaw *et al*., 2011).

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[9] Some advantages could be the following: easy availability and transportation (*e.g.* by pipes), low cost in comparison to other energy resources as well as the possibility to construct power station in any location in the world without meeting relevant barriers.

[10] Indeed, fossil fuels fall into the category of non-renewable energy sources meaning that – once they are completely used up – their formation may occur again but it will take millions of years (Curley, 2011).

[11] IPCC (2014) has defined risk as "the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of value. Risk is often represented as the probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure and hazard".

[12] IPCC (2014) has defined adaptation as "the process of adjustment to actual or expected climate and its effects. In human systems, adaptations seek to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustments to expected climate and its effects".

[13] Note that another possible way to reduce emissions of carbon dioxide is represented by the carbon capture and sequestration technologies (You, 2015).

Renewable energy is any form of energy – coming from for instance solar, wind, wave, and hydroelectric power sources – replenished by natural processes at a pace that equals or exceeds its rate of use.

Unlike fossil fuels, RES$_s$ allow the generation of "*green or clean energy*" since they do not release CO$_2$ molecules in the atmosphere when used and, therefore, do not contribute to the global warming. For such a reason, they may be acknowledged as "*sustainable energy sources*".

Nevertheless, consumption of fossil fuels in 2014 has continued increasing worldwide (British Petroleum, 2015) making them the most widely used energy sources.

In Italy, the highest share of total final energy consumptions is represented by electricity, which is primarily satisfied from fossil fuels and – to a lesser extent – from hydropower sources that generate energy by exploiting the gravitational force of falling or flowing water.

Finally, a lower contribution comes from other RES$_s$ such as solar, wind, nuclear, and geothermal ones (Figure 1.1).

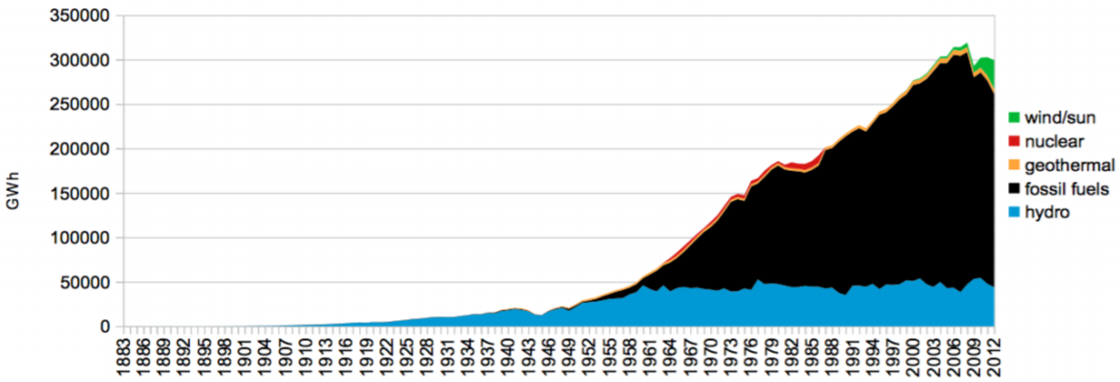

Figure 1.1. Electricity energy production in Italy from 1883 to 2012 (Source: Terna, 2013).

However, over the last years, among the various technologies based on RES$_s$, Italy recorded an extraordinary growth in the number of photovoltaic (PV) systems installed (GSE, 2013).

The word “photovoltaic” combines two terms: “*photo*” that means light and “*voltaic*” that means voltage. By making use of PV cells, a solar PV system directly converts sunlight into electricity[14].

Since the process of generating electricity occurs without emitting CO_2 molecules in the atmosphere[15], PV systems may contribute to the achievement of a sustainable development of human activities[16] by guaranteeing energy access, energy security, and climate change mitigation (Tsoutsos *et al*., 2005; Sathaye *et al*., 2011).

In the Italian context, the remarkable increase in the number of PV systems installed was mainly driven by national energy policies (Squatrito *et al*., 2014) aimed at boosting investments in renewable energy sources on the one hand and building environmental protection awareness on the other.

In particular, to lower the impact of high upfront PV costs and to encourage a large adoption of solar PV systems, Italy – as well as other countries around the world – introduced a government incentive scheme called “feed-in tariff - FIT” (the Italian equivalent is “*conto energia*”).

Under such a scheme, individuals, private and public organizations could benefit from tariffs granted over a period of 20 years.

The first FIT scheme became operative in August 2005 with the support of the GSE (Gestore dei Servizi Energetici)[17] and, after some changes over the years, it

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[14] It is important to make a distinction between solar PV systems and solar thermal systems since both of them are the two established solar power technologies. While PV systems use semi-conductor materials to convert sunlight into electricity, solar thermal systems work by using mirrors to concentrate sunlight which is used to either directly as a source of heat or to drive a heat cycle such as a sterling engine. For more details, see *http://large.stanford.edu/courses/2010/ph240/danowitz2/.*

[15] Actually low emissions can be produced during the manufacture of solar PV systems since fossil fuels are commonly used to power the supply chain (Briner, 2008). Available: *https://workspace.imperial.ac.uk/environmentalpolicy/public/BRINER%2009%20Executive%20Summary.pdf*.

[16] The term “*sustainable development*” was popularized in the report entitled “Our Common Future” – also known as “*Brundtland*” – published in 1987 where it was conceived as follows: “development which meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987).

[17] GSE is the state-owned company that promotes and supports RES_s in Italy. In particular, GSE fosters sustainable development by providing support for renewable electricity (RES-E) generation and taking actions to build awareness of environmentally-efficient energy uses.

ceased to be applied at the beginning of July 2013 after having crossed the maximum threshold of 6. 7 billion Euro.

Figure 1.2 shows both the installed PV power (MW) and the number of PV plants – in the Italian context – during the time horizon ranging from the year 2008 to 2015.

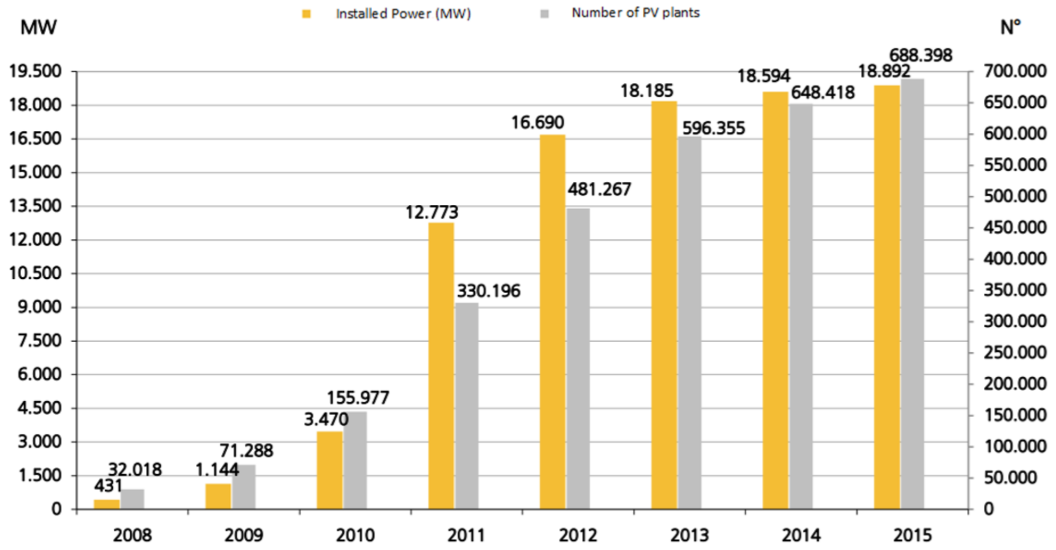

Figure 1.2. Trend in the number and installed power of PV systems in Italy (Source: GSE, 2015).

As Figure 1.2 shows, in Italy, the trend in the number and the installed power of PV systems started growing after the year 2008 although the FIT scheme entered into force three years earlier. This could have been the result of some critical issues (*e.g.*, bureaucratic barriers) that limited a greater adoption of PV systems since the first years when the FIT was already operative.

At the end of 2013, Italy accounted for 22.4% of total European PV capacity installed, therefore reaching in the period under analysis an average annual growth rate equals to 149.5%, thus more than doubling every year (Squatrito *et al.*, 2014).

However, since 2013, both the number of PV plants and the installed PV power increased at a decreasing rate in comparison to what recorded in the previous years.

Such a lower growth rate was mainly due to the end of the FIT scheme that, as already said, occurred in July 2013 (GSE, 2015).

Today, a relevant contribution in supporting the growth of the Italian PV sector may come from public organizations, which indeed are expected to take an active role in leading a change based on the use of clean energy, considering the EU targets in the matter of climate and energy (*i.e.* 20.20.20 EU package).

However, the design and implementation of public policies concerning the adoption of PV systems may be positively or negatively affected by some factors.

For instance, one of these factors may relate to the extent to which the vision and culture for sustainable development – in terms of clean energy – are greatly acknowledged and widespread in the public sector.

Another factor may refer to the existence of critical issues, which may undermine the shift towards green technologies (*e.g.*, social acceptance of solar PV technologies, or bureaucratic barriers).

Finally, the adoption of strategic management systems – to support policy-makers in formulating sustainable policies and evaluating their related results – may be considered other important "instruments" to keep into account. In this regard, one may mention the traditional Performance Management systems and the Dynamic Performance Management approach, which is a combination of the first ones with the System Dynamics methodology[18].

Based on such a background, the next section presents the objective and boundaries of this research study.

1.2. OBJECTIVE AND BOUNDARIES OF RESEARCH.

The overall objective of this research study is to enhance the design, adoption, and evaluation of public policies for PVs aimed at fostering clean energy production in the Italian context.

Based on the above objective, some preliminary choices have been done in order to narrow the scope of research.

Firstly, among the many types of technologies based on RES$_s$, the focus is on those allowing the generation of energy by means of sunlight.

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[18] Note that the "Dynamic Performance Management" approach is introduced in Section 1.4.1. In addition, it is widely discussed in Chapter 3 together with the traditional performance management systems and the system dynamics methodology.

Notably, this research study takes into account just the solar PV technology while neglects the thermal solar one which also exploits sun's energy for generating heat and, then, for serving other purposes (*e.g.* water heating).

The main reason, underlying such a first choice, lies in the fact that, as already anticipated, over the last few years, the Italian PV sector has undergone relevant changes in terms, for instance, of incentive mechanisms.

In addition, PV systems may play an important role in light of two other main factors.

The first one refers to the fact that, unlike some European countries, Italy may rely on physical features (*e.g.* good solar radiation) that may make favorable investing, installing and using PV systems.

The second factor relates to the fact that, in Italy, the greatest share of total energy consumption is attributed to electricity requirements, which may be satisfied through solar energy.

Secondly, this research study focuses only on public organizations while neglects private ones.

Public organizations are expected to take an active role in leading a change based on the use of green energy in order to provide a good example to the whole community towards the reduction of CO_2 emissions thus contributing to the achievement of a sustainable energy development in the long run[19].

Some research findings have already shown that, for citizens, it is extremely important that public organizations take the first step towards the adoption of RES_s in order to promote awareness and social acceptance of clean energy (Moula *et al.*, 2013).

Finally, in relation to public organizations, it is also important to define the institutional level of analysis: national, regional, and local ones.

This research study takes into account the national level of analysis at first, in order to point out the main targets, measures, and principles underlying the national legislative frameworks in the matter of energy.

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[19] It is also important to recognize the private sector role in promoting the reduction of CO_2 emissions. For instance, households may adopt solar insulation materials for their own buildings/houses thus reducing heat losses and energy requirements.

Afterwards, this research study takes into account the lowest institutional level of analysis, as well.

Indeed, local authorities can play a basic role in tackling mitigation and adaptation to global warming since most of energy consumptions are associated with urban activities (Covenant of Mayors).

Moreover, they form the basis for the implementation of national and international goals aimed at lowering CO_2 emissions (Kyoto Protocol Target Achievement Plan, 2005).

Based on the research objective and boundaries already introduced, the next section is devoted to present the research questions.

1.3. RESEARCH QUESTIONS.

After an introduction describing the main operational and technical features of solar PV technology, this research study is specifically addressed to discuss the three following research questions:

1. *How do traditional performance management (PM) systems contribute in supporting policy-making and performance evaluation of PV investments, installation, and usage in the Italian public sector?*
    - What are the main strengths and limitations of traditional PM systems?
2. *How may System Dynamics methodology contribute in enhancing traditional PM systems (*i.e. *Dynamic Performance Management approach) – by overcoming their limitations – and, as a result, improving PV investment policy design and related effects in terms of installation and usage?*
3. *How to apply a Dynamic Performance Management approach to the PV sector of the Municipality of Palermo to support decision-makers in outlining sustainable policies in the long run?*

1.4. RESEARCH METHODOLOGY.

Research methodology can be defined as "*the strategy, plan of action, process, or design lying behind the choice and use of particular methods*[20] *and linking the choice and use of the methods to the desired outcomes*" (Crotty, 2003: 3).

Choosing the research methodology implies the selection of the most suitable approaches in relation to the objective and questions of research study.

Three major methodological approaches might be conceptualized for conducting research in social sciences (Tuli, 2010):

- the qualitative;
- the quantitative;
- and finally the mixed approaches, involving a combination of both the qualitative and quantitative ones.

These methodological approaches differ each other for their distinct underlying philosophical and conceptual bases (*i.e.* ontological and epistemological positions[21]) as well as for the different techniques and procedures governing the research (*i.e.* research methods).

Ontological and epistemological underpinnings invariably inform the methodological strategy, which, in turn, influences the choice of the research methods to be adopted for carrying out a research investigation.

Therefore, methodology can be viewed as the bridge between ontology and epistemology on the one hand and research methods on the other.

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[20] The terms "method" and "methodology" have different meanings. Unlike methodology, the term method indicates just the tools, techniques and procedures adopted in order to collect and analyze data afterwards.

[21] Ontology and epistemology constitute the philosophical basis of the research study. In particular, ontology is the branch of philosophy that focuses on the "assumptions that are made about the nature of social reality, what kinds of things do or can exist, the conditions of their existence, and the way they are related" (Blaikie, online definition). Theories about the nature of social reality fall into two major categories: the researcher considers what exists either as an external or independent reality from people's perceptions or based on social and human conceptions.

Epistemology regards the philosophical study of knowledge and "the grounds upon which we believe something to be true" (Oliver, 2010:35). The most noteworthy branches in epistemology include historical perspective, empiricism, idealism, rationalism and constructivism.

Ontology, epistemology, and methodology might give rise to a certain paradigm[22], which constitutes a distinct world-view (Kuhn, 1962).

In broad terms, it is possible to discern four major paradigms in the field of social science research: the positivism[23], the post-positivism[24], the interpretativism[25] and the critical[26] ones (Hammett *et al*., 2014), which present different philosophical foundations and, then, distinct research methodologies.

For instance, ontological and epistemological perspectives based on the assumption that reality is objective and, then, scientifically explainable would lead to the positivist paradigm requiring research methodologies able to measure variables and to test hypotheses. In such a case, the quantitative methodological approaches[27] (*e.g.,* experiments and surveys) may be considered the most appropriate ones than other approaches (*e.g*., qualitative approaches).

Conversely, the interpretativist paradigm – characterized by the basic assumption that reality is multiple and socially constructed by participants (Guba & Lincoln, 1994) and, then, susceptible of understanding rather than explanations – would privilege qualitative methodological approaches[28] (*e.g.,* phenomenology, case study, and grounded theory).

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[22] In his celebrated essay "*the structure of scientific revolutions*" published in 1962, the philosopher Thomas Kuhn established the basis for his methodological paradigm. He defined the term "paradigm" as "universally recognized scientific achievements that, for a time, provide model problems and solutions for a community of researchers". The three major dimensions of a paradigm are represented by the ontological, epistemological and methodological ones.

[23] The positivism or scientific paradigm is based on the ontological assumptions that the reality is external to the researcher and objective. Therefore, knowledge is objective and can be generated by adopting a deductive approach (epistemological assumptions).

[24] The post-positivism paradigm arose as a reaction against the positivism one and its ontological assumptions are based on a critical realism with epistemological perspectives based on the possibility to achieve results that are probabilistically true (and not "true" as assumed by the positivists) and the definition of temporary rules.

[25] The interpretativist paradigm, also called "anti-positivist", is based on the ontological assumptions according to which the reality is subjective rather than objective since it is constructed by individual interpretations and their interactions. Such an approach aims at understanding (and not explaining) the reality and, consequently, knowledge can be gained through an inductive process (epistemological perspective).

[26] Finally, critical realists view structure and agency as mutually constitutive and seek to understand and explain how different causal mechanisms exist and work (Hammett *et al*., 2014: 21).

[27] Notably, "quantitative research is an approach for testing objective theories by examining the relationship among variables. These variables, in turn, can be measured, typically on instruments, so that numbered data can be analyzed using statistical procedures" (Creswell, 2003:2).

[28] Conversely, "qualitative research is an approach for exploring and understanding the meaning individuals or groups ascribe to a social or human problem" (Creswell, 2003: 2).

On the basis of the foregoing, in this research study, a mixed methodological approach – based on both the qualitative and quantitative approaches – has been chosen.

As for the qualitative research methodology, the case study approach[29] is adopted[30], which is underpinned by constructional ontological and interpretativist epistemological assumptions.

Beside the case study, a Dynamic Performance Management (DPM) approach[31] – resulting from the combination of System Dynamics (SD) methodology[32] with the traditional performance management (PM) systems – is also adopted.

Among the different strands of SD practices (*e.g.*, the positivist, the post-positivist, the critical pluralist, and the constructivist paradigms), the critical pluralist approach is privileged, which is grounded on the realist ontological position, meaning that a real external world does exist although it can be known just to a certain extent.

As regards the epistemological bases, the subjective position prevails, which is grounded on the idea that such "a real world can be accessed only by means of subjective mental models" (Pruyt, 2006: 21). Notably, the epistemological underpinnings come from the "general system theory"[33] (Bertalanffy, 1968) which, in turn, dates its origin back to the school of thought known as "structuralism"[34].

Based on such ontological and epistemological bases, quantitative results are to be interpreted in a "qualitative way" since the main interest is to better understand

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[29] The case study approach is introduced in Section 1.4.2.

[30] Note that this research study is also based on a critical analysis of literature and legislative frameworks.

[31] The Dynamic Performance Management approach is introduced in Section 1.4.1.

[32] See *http://www.systemdynamics.org/*.

[33] The biologist L. von Bertalanffy proposed the "general system theory" as reaction against the "reductionism". He emphasized the concept of "relationships" among different variables or parts of a system as to the model of "circularity" according to which each element affects another one which, in turn, feeds into the previous one back. The privileged perspective is the holistic one where the "whole is greater than the sum of its parts" because of the existence of relationships among the parts (Crespi, 1985: 306). The system theory mainly analyses the dynamics of open systems that present continuous relationships with the surrounding environment.

[34] The structuralism might be considered as the generalization of the concept of "structure" of Marx. Such a movement, developed from Lévy-Strauss and De Saussure's anthropological and linguistic studies, tried to identify the structures underlying the dynamics of all cultural phenomena in order to understand the reality.

the reality that one is looking at (Pruyt, 2006) rather than trying to find an objective explanation.

Although the qualitative and quantitative methodological approaches chosen for conducting this research study present distinct features, both of them have a common denominator represented by their philosophical bases according to which reality is not objective but rather it strictly depends on the personal perceptions, world-views, and value systems of persons involved.

1.4.1. *Dynamic Performance Management approach: a short introduction.*

The approach adopted in this research study is the "*Dynamic Performance Management*", which is based on two methods of inquiry: "Performance Management" and "System Dynamics" modeling[35] (Bianchi, 2015).

Performance Management (PM)[36] may be defined as a "system that generates performance information through strategic planning and performance management routines and that connects this information to decision venues, where, ideally, the information influences a range of possible decisions" (Moynihan, 2008: 5).

On the other hand, System Dynamics (SD) is a methodology able to support decision-makers in understanding and framing the dynamic complexity[37], which characterizes the systems in which they operate.

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[35] Both of these methods are widely presented in Chapter 3. Here, a short introduction is provided.

[36] According to Bianchi (2013), the term "performance management" means "understanding the results of an organization, secondly understanding the factors impacting on results, thirdly understanding the levels on which it is possible to act in order to influence the factors that affect the results and also understanding how the results will affect future performance".

[37] The capacity of the human mind for "formulating and solving complex problems is very small compared to the size of the problem whose solution is required for objectively rational behavior in the real world or even for a reasonable approximation to such objective rationality" (Simon, 1957: 198). Bounded rationality and limited information might curtail the potential for learning in a world featured by growing dynamic complexity, with the risk to make decision-makers unable to design and implement effective strategic action plans or policies thus leading organizations to poor performance or other dysfunctional effects in the medium/long-term horizon.

Although SD methodology encounters a thriving application in different fields, it may be a powerful tool whenever applied to public sector organizations since they are featured by high degrees of complexity[38].

As for this research study, a DPM approach may contribute towards the achievement of the research objective for the following reasons.

Firstly, as already said, the focus of this research study is on public organizations, which need tailored approaches to their own characteristics in order to enable their decision-makers to deal with the dynamic complexity.

Secondly, previous research studies (Bianchi, 2012a; Bianchi, Cosenz & Marinković, 2015) have shown how SD methodology may enhance PM by supporting decision-makers in designing sustainable policies and assessing their related impacts in both time and space. This is made possible by making use of proper tools mainly borrowed from the SD methodology (*e.g.*, causal loop diagram).

Therefore, the application of a DPM approach to the PV sector may allow one to understand how it may contribute to foster the pursuit of a sustainable development in terms of clean energy.

As for the application of the DPM approach to the PV sector, two main choices have been done.

First, this research study primarily focuses on the "instrumental view of performance"[39], which is based on three key concepts *i.e.* strategic resources, performance drivers, and end-results[40].

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[38] Indeed, "public sector is featured by different attributes that sharply differentiate it from the private sector such as difficulties in achieving consensus on the outputs of delivered services, identifying and measuring outcomes corresponding to such outputs, communicating with different stakeholders and achieving a sustainable performance development" (Bianchi & Williams, 2015).

[39] One might identify three complementary views of performance management that is the objective, the instrumental and the subjective ones (Bianchi, 2012a). For a more detailed description of these views of performance, see Chapter 3.

[40] Strategic resources are represented as stocks (*alias* levels) since they symbolize the state of the system (Sterman, 2000). In particular, they are subjected to accumulation and depletion processes as a result of the dynamics of their related flows (*i.e.* inflows and outflows). Hence, end-results, typically represented as flows, might be considered what determines changes into the corresponding level of strategic resources over a given time span. Finally, end-results are tightly affected by their corresponding performance drivers or intermediate results that, as already stated, depend on the endowment of their related strategic resources. These concepts are better explored in Chapter 3.

Identifying the causal effect relationships between strategic resources, performance drivers and end-results may provide public decision-makers with proper “lenses” needed to frame the relevant system structure underlying performance (Pekkola & Rantanen, 2014; Bianchi *et al*., 2015) and, then, to design alternative strategies.

Second, the DPM approach is not applied to reproduce a given past problem (*i.e.* reference mode) related to the PV sector but it is applied in order to perform “scenario analysis” that may enhance a feed-forward approach to policy-making (learning environment foresight model)[41].

Finally, in order to apply a DPM approach, two tools for system thinking[42] are adopted, *i.e.*:

- the causal loop diagram (CLD);
- the stock and flow model (S&F).

CLD is a qualitative diagram that shows the causal effect relationships among the variables of interest (*i.e.*, strategic resources, performance drivers and end-results) without making use of quantitative data. It is developed through an *ad hoc* software called “Vensim” [43].

Unlike CLD, the S&F is a quantitative model since the variables are numerically expressed and, therefore, it allows performing simulations in order to better support public decision-makers’ strategic learning processes.

S&F is built by making use of the modeling and simulation software “Ithink”[44] that allows modeling not only mathematically but also graphically, which is very intuitive and illustrative (Arndt, 2006).

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[41] Indeed, one may identify two main contexts where “SD may support PM to frame dynamic complexity, *i.e.*: 1) to assess *current* performance levels and to diagnose the current scenario patterns underlying the existing state of an organizations; 2) to assess *future* performance levels where planning is expected to enhance the outline and implementation of strategies to manage sustainable organizational growth or restructuring policies to fix crises” (Bianchi, 2015: 41).

[42] According to Richmond, system thinking contains four elements: thinking in models which includes the ability to construct models and transfer the gained knowledge to real situations; dynamic thinking that enables anticipation of future behavior of systems with delays, oscillations and feedback loops; integrated thinking and acting successfully in complex situations by choosing the right decision, well considered (Richmond, 1993; Arndt, 2006).

[43] For more details, see *http://vensim.com/*.

[44] For more details, see *http://www.iseesystems.com/softwares/Business/IthinkSoftware.aspx*.

Moreover, some appropriate structure tests (*e.g.*, dimensional-consistency tests) are carried out in order to enhance the validity of the model[45].

As for the data needed to develop both the CLD and the S&F model, they come from two main sources:

- *primary data* collected through semi-structured interviews;
- *secondary data* including both data emerging from the analysis of the existing literature and data retrieved from official reports and other documents (*e.g.,* Istat database).

Finally, the application of a DPM approach to the PV sector is based on a case-study analysis.

1.4.2. *Case study methodology: outlining the research method design.*

Case study is a methodological approach for carrying out qualitative research in social sciences and multiple formal definitions can be found in literature.

Yin provided a technical definition of case study by outlining the scope of such an approach. Thus, case study has been defined as an “empirical inquiry that investigates a contemporary phenomenon within its real-life context” (1984: 23).

Case study approach has been also conceptualized as a “systematic inquiry into an event or a set of related events, which aims to describe and explain the phenomenon of interest” (Bromley, 1990: 302; Zucker, 2009).

Furthermore, according to Merriam, case study can be defined as “an examination of a specific phenomenon, such as a program, an event, a process, an institution, or a social group” (1998: 9).

Although the above formal definitions present different facets, all of them have a common denominator represented by the investigation, description or explanation of a given phenomenon of interest that might relate to institutions, individuals, or groups of individuals as units of analysis.

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[45] Such an activity goes under the name of “validation” and it indicates an “on-going mix of activities embedded through the iterative model-building process” (Lane, 1998). To this end, Forrester and Senge (1980) have identified three kinds of tests for model validation *i.e.* tests of model structure, tests of model behavior and finally tests of policy implementation.

Beside the above definitions, there are also as many distinct types of case study approaches. For instance, one might distinguish between single and multiple-case studies[46] on the one hand and descriptive, exploratory, and explanatory case study approaches[47] on the other.

Moreover, another possible distinction is the one proposed by Stake who recognizes three different types of case study approaches *i.e.* the intrinsic, the instrumental and the collective ones[48] (1995).

As far as this research is concerned, the case study refers to the Municipality of Palermo, the regional capital of Sicily (Italy), which accounts almost 680,000 inhabitants.

The Municipality of Palermo has been one of the first Italian municipalities to undertake initiatives, workshops and projects (*e.g.*, Covenant of Majors, or MedClima) aimed at improving its energy efficiency standards through, for instance, the adoption of PV systems to be installed on its public buildings. However, over the last few years, it has recorded a decreasing trend in the PV capacity installed.

In particular, the case study of Palermo Municipality presents the main following features:

- the phenomenon of interest is represented by the identification of the main critical issues affecting the adoption of PV systems and, then, the production of clean energy. Based on this, a DPM approach is applied in order to overcome such issues by outlining sustainable policies;

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[46] A single case study focuses only on a single case while multiple-case studies include two or more cases within the same study (Laws & McLeod, 2004).

[47] Descriptive case study is used to describe an intervention or phenomenon and the real-life context in which it occurred. Exploratory case study is used to explore those situations in which the intervention being evaluated has no clear, single set of outcomes. Finally, "explanatory case study would be used if you were seeking to answer a question that sought to explain the presumed causal links in real-life interventions that are too complex for the survey or experimental strategies" (Yin, 2003: 5).

[48] In the first situation, the case is studied for its intrinsic genuine interest without pursuing the aim of building a theory. In the second situation, a case is chosen to accomplishing or understanding something else. Finally, in the third situation, several cases are studied to form a collective understanding of the issue or question (1995).

- the units of analysis are those departments or organizational areas directly involved in the phenomenon under investigation (*e.g.* the environmental, and budget departments);
- just this case study is included into the research scope (*i.e.* single case study) in order to investigate the phenomenon as a whole;
- the aim is to describe the phenomenon in its real-life context (*i.e.* descriptive case study);
- last, but not least, case study is considered in light of its intrinsic genuine interest that is for better understanding the phenomenon itself (*i.e.* intrinsic case study) rather than for supporting the comprehension of other phenomena.

The major grounds – underlying the choice of the case study – may be summarized as follows:

- firstly, the case study approach – unlike historical studies – enables the analysis of contemporary events (Yin, 1984) and, therefore, it can be considered "fit for the purpose" of this research since the aim is to understand the phenomenon of interest in light of the current context;
- secondly, the case study approach allows the investigation of the phenomenon of interest in its natural context;
- finally, the case study allows gathering data "in the field". Indeed, in order to better understand the main critical issues related to the adoption of PV systems in the Municipality of Palermo, the case study approach may allow working directly "in the field" in close collaboration with the main key "actors" involved.

As regards data collection, the case study of Palermo Municipality relies on both primary and secondary data sources[49].

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[49] Notably, primary data can be defined as "data you collect specifically for your research project" while secondary data are "those that were originally collected for some other purpose" (Saunders *et al.*, 2012: 84). For instance, examples of methods for collecting primary data are represented by interviews or participants observations while examples of methods for gathering secondary data are reports, magazine, and newspapers.

In particular, the first ones mainly consist of qualitative data while the second ones include both qualitative and quantitative data.

Collecting and using both primary and secondary data may allow:

- gaining a comprehensive picture of the research phenomenon under investigation;
- enhancing construct validity *alias* triangulation and, then, the reliability of data[50].

As far as the primary data sources is concerned, data are collected through semi-structured[51], face-to-face, and one-to-one interviews with those “actors” (*e.g.* Energy Manager) who may provide key information for better understanding the phenomenon under analysis.

Interviews are considered a key source of case study information (Paré, 2004) since they might provide significant details about respondents’ experiences, their perceptions and viewpoints thanks to the personal nature of dialogue (Berger, 1998).

As for this research study, semi-structured interviews are conducted by following a three-step interview process *i.e.* the planning phase, the interview phase and finally the data analysis phase. Even though semi-structured interviews are more flexible than the structured ones, they require rigorous preparation. Therefore, the first phase envisages the drawing up of an interview plan that serves as a guide during the whole interview process. Such a first step includes as follows: the identification of key informants, the development of questions, the choice of question types (primarily open-ended questions) and the grouping of questions in themes according to a logical sequence. The interview phase entails the actual execution of the interview that starts with an introduction of the context to interviewee before presenting the topics to be discussed. Then, the selected questions are asked and the respondent’s answers are noted down. Finally, during the last stage, data emerging from the interviews are analyzed to gather insights.

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[50] Indeed, there are different ways to increase construct validity when doing case studies. One of this is “the use of multiple sources of evidence, in a manner encouraging convergent lines of inquiry and this tactic is relevant during data collection” (Yin, 2003: 47).

[51] Basically, interviews can be structured, semi-structured or unstructured. In particular, semi-structured interviews consist of “more or less open-ended questions are brought to the interview situation in the form of an interview guide” (Flick, 1998: 94).

As for the secondary data sources, they primarily consist of:

- official reports (*e.g.*, GSE reports, Sustainable Energy Action Plan of the Palermo Municipality);
- documents published on official websites (*e.g.*, the official website of the Municipality of Palermo, and the GSE website) or paper-based archive materials;
- and statistical databases (*e.g.*, Istat database).

Finally, specific techniques of data analysis[52] are adopted for both primary and secondary data collected[53].

The analysis of primary data is carried out by applying the "thematic analysis" technique.

Specifically, such a technique is performed through a coding process (*i.e.* identification of open and axial coding)[54] that aims at identifying major themes[55] and causal effect relationships.

Credibility and, then, reliability of analyzed data is enhanced through the "member checks" procedure[56] (*alias* "member or respondent validation technique") and the afore-mentioned "triangulation".

Finally, analysis of secondary data involves a critical review of the main collected documents as well as the application of the thematic analysis technique (*e.g.* coding process of online documents, or newspaper articles) whenever needed in order to identify the major causal relationships among the emerging categories.

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[52] Data analysis involves "working with data, organizing it, breaking it into manageable units, synthetizing it, searching for patterns, discovering what is important and what is to be learned, and deciding what you will tell others" (Bogdan & Biklen, 1982: 145).

[53] Qualitative research requires a cyclical approach in which the collection of data affects the analysis of data which, in turn, affects the further collection of data (Westbrook, 1994: 245). Therefore, "data collection and analysis form an integrated activity" (Mellon, 1990: 24).

[54] Actually, the coding process is common to many other qualitative data analysis methods such as, for instance, the Grounded Theory (Glaser & Strauss, 1967). Briefly, such a process implies the definition of open, axial and selective coding which are directly developed from data analysis. This research study takes into consideration just the first two levels of coding *i.e.* the identification of open and axial coding. Indeed, the aim of coding process is not to generate a new theory but rather to describe or interpret the major themes found out.

[55] In particular, "the term "theme" refers to clusters of categories that share some commonality such as reference to a single issue" (Westbrook, 1994: 246).

[56] Member checking is a procedure that might occur during or near the end of the research project. Basically, it may involve sharing all of the findings with the participants, and allowing them to critically analyze the findings and comment on them (Creswell, 2007; Harper, 2012).

1.5. CONCLUDING REMARKS.

In this Chapter, the need and reasons to move towards a more environmentally sustainable energy system have been discussed.

The recourse to technologies based on RESs is considered an affordable solution since these latter can contribute to reduce climate changes while still satisfying energy demand.

In particular, among the various technologies based on RESs, this research study focuses on the solar PV technology within the Italian public sector, for reasons introduced earlier.

Three research questions and two methodological approaches have been outlined. These latter consist of an application of a DPM approach to the PV sector as well as an analysis of a case study based on the Municipality of Palermo.

The next Chapter provides a deeper understanding of the solar PV technology and the role public organizations may play in unleashing energy efficiency actions.

CHAPTER 2

SOLAR PHOTOVOLTAIC TECHNOLOGY: THE ROLE OF PUBLIC ORGANIZATIONS IN THE ITALIAN CONTEXT

This chapter introduces the solar PV technology by describing its main operational and technical features. Afterwards, the role of solar PV technology in the Italian context is outlined within the "National Renewable Energy Action Plan". In particular, the contribution that public organizations may provide in unleashing energy efficiency actions is emphasized. The discussion of some bureaucratic, social, and financial issues – which may affect the adoption of PV systems in the public sector – follows. Finally, the chapter ends with an outline of the deployment of PV systems in the Italian public sector.

2.1. INTRODUCTION TO SOLAR PHOTOVOLTAIC TECHNOLOGY.

In the Italian current context where electricity is used more and more as an energy source, solar PV systems may play a remarkable role in the field of technologies based on RESs.

PV systems allow the direct conversion of solar radiation into electricity, without concern for energy supply and environmental harm since fossil fuels are not used during the conversion process (Papadopoulou, 2011).

Notably, such a conversion process takes place thanks to the so-called "*photovoltaic effect*"[57] (Solanki, 2013), which was first observed by the French physicist A. E. Becquerel in 1839[58]. That is why it is also known as "Becquerel effect".

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[57] Notably, the "photovoltaic effect" might be defined as "the generation of a potential difference at the junction of two different materials in response to electromagnetic radiation" (Jäger *et al.*, 2014: 23).

[58] Note that the concept of "photovoltaic effect" is strictly related to the concept of "photoelectric effect". In 1905, the German physicist A. Einstein theorized the "*photoelectric effect*" by mathematically defining an equation for light.

Notably, light is composed of energy quanta, called "photons" and, according to Einstein's mathematical equation, energy of a photon (E) would be equal to the frequency of the light (v) multiplied by a constant (h). Hence, the mathematical equation would be: $E= hv$.

Basic units called solar cells[59] – made up of semiconductor materials (*e.g.* silicon) and constituting the heart of a solar PV system – are responsible for such a photovoltaic effect (Krauter, 2006).

Semiconductor materials allow the absorption of particles of sunlight called "*photons*", which are used to hit electrons occupying a band of energy known as "*valence band*" (Knier, 2012).

When photon energy exceeding a certain threshold, called "*band gap energy*" (*Eg*), is applied to an electron[60], a movement – from the initial energy level of the electron *i.e.* the valence band to a higher energy level called "*conduction band*" – takes place[61].

In the conduction band, a special contact drives electrons to the external circuit. Such a movement generates "*electric energy or current*" that can be used for serving different purposes *e.g.* pumping water or meeting lighting requirements (Abella *et al*., 2003).

Subsequently, electrons can return to their initial energy band with the same level of energy that they had at the beginning of such a process.

Solar PV technology presents undoubted advantages that are mainly related to its environmental benefits.

However, one may also identify some disadvantages, which are listed in the table below, together with the main advantages (Table 2.1).

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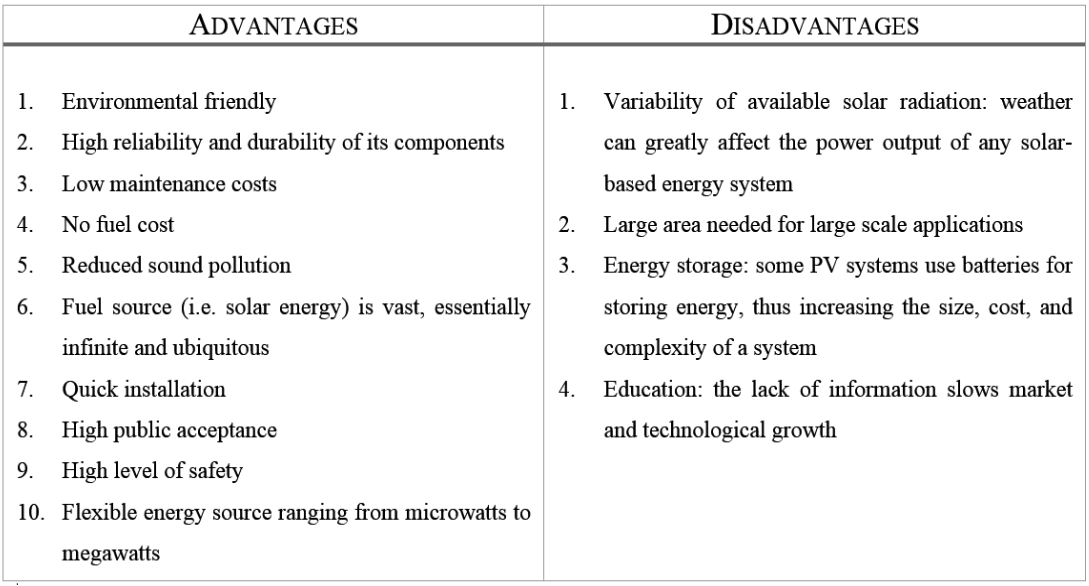
[59] A more detailed description of such basic units, *i.e.* solar cells, is provided in the next section.

[60] That is $E = hv > Eg$.

[61] Basically, the band gap energy is given by the difference between the conduction energy edge (Ec) and the valence energy edge (Ev). Thus, $Eg = Ec - Ev$.



ADVANTAGES	DISADVANTAGES
1. Environmental friendly 2. High reliability and durability of its components 3. Low maintenance costs 4. No fuel cost 5. Reduced sound pollution 6. Fuel source (i.e. solar energy) is vast, essentially infinite and ubiquitous 7. Quick installation 8. High public acceptance 9. High level of safety 10. Flexible energy source ranging from microwatts to megawatts	1. Variability of available solar radiation: weather can greatly affect the power output of any solar-based energy system 2. Large area needed for large scale applications 3. Energy storage: some PV systems use batteries for storing energy, thus increasing the size, cost, and complexity of a system 4. Education: the lack of information slows market and technological growth

Table 2.1. Advantages and disadvantages of photovoltaics (Source: Adaptation from Solar Energy International, 2006, p.3).

A more detailed description of the PV systems is given in the next subsections.

2.1.1. *Fundamentals of solar photovoltaic technology*.

From a technical viewpoint, a solar PV system consists of three main subsystems, *i.e.*:

- the PV modules or arrays;
- the balance of system (BOS);
- and finally the electrical load.

As for the PV modules, they consist of large devices in which solar cells[62], responsible for capturing sunlight, are assembled to each other.

Depending on the semiconductor material used (*e.g.* crystalline silicon or thin-film), an individual solar cell usually generates "direct current and power typically

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[62] One may identify two major types of solar PV cells: crystalline silicon (c-Si) wafer-based solar cells and thin-film solar cell technologies (Poortmans & Arkhipov, 2006; Razykov *et al*., 2011; Shakya, 2011). The first ones can, in turn, be distinguished into mono-crystalline and multi-crystalline silicon ones (Jäger *et al*., 2014).

between 1 and 2 watts (W) that is hardly enough to power the great majority of applications" (Prasad & Snow, 2005: 25).

However, in order to generate a specific voltage or to power a wide variety of electrical equipment, individual solar cells need to be grouped together thus giving form to greater units called "PV modules" or "power generators"[63].

The standard PV module is often made up of "36 individual solar cells, each 10x10 cm^2, connected in series, mechanically supported and protected by corrosion" (Wright, 2002: 341).

The average lifetime of a PV module is 25 years although the degradation of its components might occur throughout such a time period as a result of external stress coming from various sources (*e.g.*, temperature changes, mechanical stress, moisture, humidity, and irradiance).

To lessen the likelihood that such a degradation process takes place and, then, to improve the performance of PV modules, some harsh tests[64] – defined by standards[65] – are performed before they start operating.

PV modules consist of different layers (Figure 2.1), each of them having a specific function, and built by making use of particular materials.

A very thick soda-lime glass is used to provide mechanical rigidity and protection to the module while being transparent for the light. Glass must be tempered to increase the resistance to possible impacts and it must have low iron content to avoid low light transmission (Alonso *et al.*, 2012).

The cell matrix is sandwiched between two layers of encapsulants. The most common material used is "ethylene-vinyl-acetate" (EVA), which is a thermoplastic polymer.

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[63] Note that solar cells can be connected in different ways, such as in series or parallel connections. In a series connection, the voltages add up while the current does not but rather it is determined by the photocurrent in each solar cell. Whenever solar cells are connected each other in parallel, the voltage is the same over all solar cells, while the currents of solar cells add up (Jäger *et al.*, 2014).

[64] Some examples of texts are the following: thermal cycle, UV testing and damp heat (van der Wel *et al.*, 2011).

[65] For more details, see *http://www.tuv-intercert.org/it/i-nostri-servizi/prodotto/energie-rinnovabili/energia-solare/iec-61215-iec-61646.html#.VkHaObcvdD8.*

Finally, the outer layer is usually a composite plastic sheet acting as a barrier against humidity and corroding species.

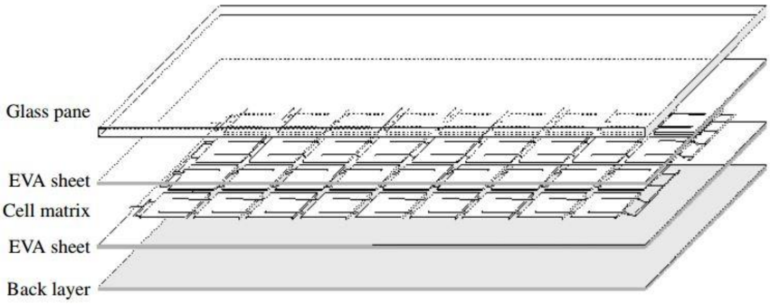

Figure 2.1. Typical layers of a PV module (Source: Alonso *et al*., 2012).

PV modules can be electrically connected and mounted on a supporting structure that, in turn, gives rise to another even larger structure, technically known as "PV panel".

Finally, PV arrays represent the highest level of assembly for a complete PV system.

In particular, PV arrays are made up of two or more strings of solar PV panels linked to each other in parallel where strings, in turn, arise from series connections of two solar PV panels.

The main components of a PV system, ranging from the smallest unit *i.e.* the solar cell to the greatest level of aggregation *i.e.* the PV array, are illustrated in Figure 2.2.

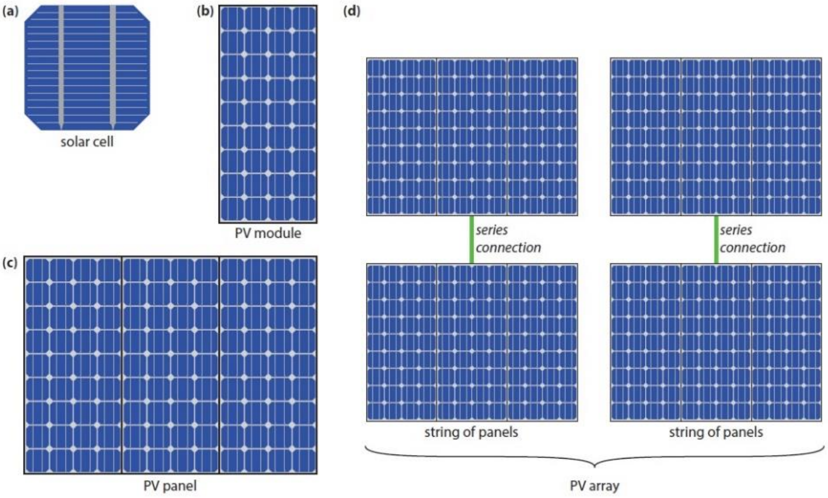

Figure 2.2. Representation of (a) a solar cell, (b) a PV module, (c) a PV panel and (d) a PV array (Source: Jäger *et al*., 2014).

As for the “balance of system” (BOS), one may identify other PV components (Jäger *et al*., 2014; Balfour *et al*., 2013), which guarantee the operation of a PV system, *i.e.*:

- *mounting structures* used to fix the PV modules, to prevent potential stealing and to guarantee easy access for maintenance operations;
- *batteries* used to store energy in case of solar PV systems not connected to the electrical grid (Wenham *et al*., 2011)[66];
- *charge regulators or controllers* used to protect the batteries from overcharge or excessive discharge;
- *cables* used to connect the different components of a solar PV system to the electrical load;
- *inverter* used to transform the direct current (DC) electricity, generated from the PV modules, into alternating current (AC) electricity in order to provide power to the electrical load (Boxwell, 2015).

Indeed, the electrical load may be considered another subsystem of a solar PV system including all those appliances, lights or equipment that can be powered by means of sunlight.

The electrical load has to be taken into account during the planning phase of PV investments since it drives the choice of the most suitable type of solar PV systems to be installed.

To this end, the basic configurations of solar PV systems are presented in the next subsection.

2.1.2. *Basic configurations of solar photovoltaic systems*.

Depending on the system configuration, one may distinguish two major types of solar PV systems *i.e*. the stand-alone and the grid-connected ones (Figure 2.3).

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[66] Since batteries store energy, they allow tackling both diurnal and seasonal fluctuations. Thus, they deliver energy during the night or in periods of adverse climate conditions. Likewise of solar panels, they can be connected together – in series or parallel – to form a larger “battery bank” (Boxwell, 2015).

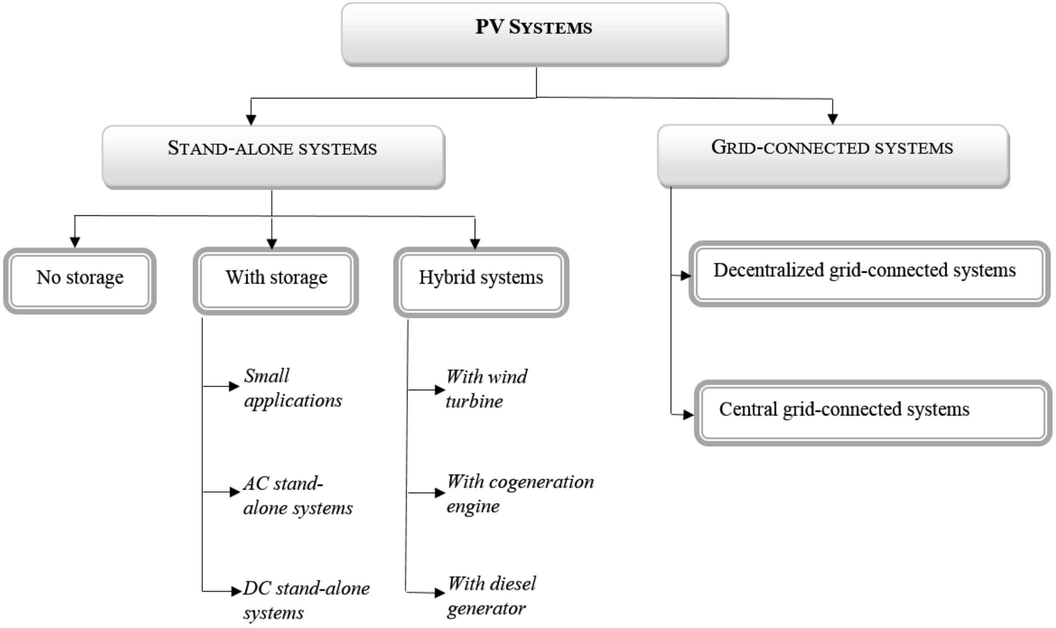

Figure 2.3. Main configurations of solar PV systems (Source: Deutsche Gesellschaft für Sonnenenergie, 2008).

Stand-alone systems represent the first cost-effective configurations of solar PV systems[67].

They can be mainly found in remote areas where "utility lines are uneconomical to install due to terrain, the right-of-way difficulties, or the environmental concerns" (Papadopoulou, 2011: 38). Thus, stand-alone systems may be a good solution to overcome the energy supply difficulties.

Stand-alone PV systems rely on solar power only, they are designed to operate without having a connection to an electrical (public) grid and three main types can be identified, *i.e.*:

- *stand-alone systems without storage* representing the simplest configuration characterized by lower installation costs since some components are not needed (*e.g.*, batteries, and inverters)[68]. Therefore, they may have limited applications (*e.g.* water heating);

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[67] A wide set of stand-alone applications might be observed that range from the simple solar calculators and battery charges to mobile systems such as cars, boats, mountain cabins and traffic signals.

[68] See Goetzberger & Hoffmann, 2005; Rekioua & Matagne, 2012.

- *stand-alone systems with storage* that are more complete and costly configurations than the previous ones since batteries and other components are required to supply energy at night, as well;
- *hybrid stand-alone systems*[69] that combine different methods of electricity generation *i.e.* diesel/fossil-fuelled generators with RES-based technologies (*e.g.* wind turbines). That is why they are more sophisticated than the traditional stand-alone systems and more expensive than the grid-connected ones (Papadopoulou, 2011; Jäger *et al.*, 2014).

Unlike the stand-alone systems, the grid-connected ones are connected to the electrical grid and they are widely used for building applications thanks to their ability to generate medium and high-grade energy.

In particular, one may identify two main types of grid-connected PV systems *i.e.* the decentralized grid-connected systems and the central grid-connected ones.

The first ones usually provide small-medium power energy and they do not require the use of batteries for their operation[70].

The central grid-connected systems provide medium or high power energy and they operate like central power stations where a large PV array is directly linked to the transmission lines (Stapleton & Neill, 2012).

Both the stand-alone and the grid-connected systems may be mounted in different ways. Such an aspect is discussed in the next subsection.

2.1.3. *Mounting systems for solar photovoltaic technology*.

There are two main options for positioning PV systems in order to capture solar radiation, *i.e.*:

- roof installations (*i.e.* roof-mounted systems);
- and ground installations (*i.e.* ground-mounted systems).

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[69] Hybrid systems might “deliver from 1 kWh per day to typically 10-100 kWh per day” (Bopp *et al.*, 1998: 272) and can be implemented in both remote and urban areas.

[70] Here, the electrical grid itself acts like a “storage unit or battery” where any excess of PV electricity – generated from the PV module but not absorbed by the electrical load – flows into it. Conversely, additional electricity energy is drawn from the electrical grid in case of insufficient PV electricity for supplying the electrical load.

The first option often represents the most conventional way to position PV modules since no extra space is needed[71].

Such an option also includes the alternatives of *integrating* the modules into roofs (roof-integrated systems) or into building facades (building-integrated photovoltaic systems).

In case of roof-integrated systems, PV modules would perform a double function being, at the same time, “roof” and “electricity generation source”. Moreover, although they may be quite expensive, they reduce the visual impact of PV modules and, therefore, they can facilitate the obtaining of permissions.

As for the building-integrated photovoltaic (BIPV) systems, they might present some additional benefits (Prasad & Snow, 2005: 12), *i.e.*:

- the building itself becomes the PV structure;
- the BIPV components displace the conventional building materials thus reducing the installation costs;
- finally, the integrated systems may increase both market and social acceptance of solar PV technology.

Notwithstanding, they may present some drawbacks associated with their vertical orientation, which may affect the PV module efficiency.

Finally, the ground-mounted option is mainly chosen in case of large utility-scale PV systems and it allows siting the PV modules at the optimum orientation and, thereby, reaching the maximum electricity output.

Additionally, such an option allows an easy access to the PV systems for carrying out regular maintenance operations.

However, they may present two main disadvantages in terms of social acceptance[72] (aesthetic objections and ground disturbance) and high PV installation costs in case of additional mounting structures.

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[71] In particular, PV systems can be mounted on sloped or flat roofs. In this last case, highly innovative technologies may be needed such as, for instance, the use of a solar PV tracker system that rotates PV panels in order to optimize their performance. For more details, see *http://www.solarpvtech.com/solar-pv-systems/310147-solar-panel-tracker-system* *http://www.williamsrenewables.co.uk/solar-pv/solar-trackers/.*

[72] Such an issue is better discussed in Section 2.4.2.

2.2. PHOTOVOLTAIC TECHNOLOGY IN THE ITALIAN CONTEXT: SOME PRELIMINARY CONSIDERATIONS.

In Italy, “the first evidence of interest, from single scientists, towards PV technology can be traced back to the 60s but it is only after the oil crisis of 1973 that this interest became a reality through wide range of PV development programs” (Giagnorio *et al*., 2007: 41).

The promotion of electricity generated from solar PV technology was recognized as a priority measure for reasons of energy security, diversification of energy supply, and environmental protection.

Nevertheless, at the beginning, in Italy, the wide-scale adoption of solar PV technology occurred slowly. It is extremely likely that the main reason underlying such an initial limited deployment had much to do with the high upfront costs of PV technology.

Therefore, in order to boost the adoption of solar PV systems, Italy launched some initiatives, development projects, and incentive mechanisms such as, for instance, the BIPV project[73], the Italian roof-top programme[74] as well as the feed-in tariff scheme[75], which became operative in 1999, 2001, and 2005, respectively (Maddalena & Padalino, 2008).

Thanks to the above initiatives and projects, the number of installed PV systems started increasing more and more and, in just a few years, the Italian PV sector witnessed a considerable growth.

Indeed, the number of PV systems and the installed power ranged from 7,647 and 87 MW in 2007 to 591,029 and 18,053 MW in 2013, respectively (GSE, 2013).

In the Italian context, the increased generation of electricity from solar energy represented also an important part of a package of measures needed to comply with

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[73] The project aimed at a threefold objective *i.e.* experimenting the architectural integration of PV modules on roofs and facades, evaluating plant performance as to verifying the effectiveness of the technical solutions adopted. Such a project involved both Municipalities and Universities of some important Italian cities where some small grid-connected pilot plants were installed on their public buildings (Castello *et al*., 2004).

[74] It embodied two major projects *i.e.* the national roof-top programme for public buildings on the one hand and the regional roof-top programme on the other. Such projects aimed at encouraging the development of small grid-connected systems and promoting a wide diffusion of building-integrated PV applications all over the Country, respectively (Castello *et al*., 2004).

[75] A detail of the feed-in tariff schemes is provided in the next sessions.

targets fixed at the upper institutional level *i.e.* the European one (*e.g.*, “20.20.20 climate & energy package”)[76] in line with a multi-level governance approach[77].

Such a multi-level governance approach aimed at furthering the development of the Italian PV sector through the implementation of effective learning and cooperation processes across different institutional levels.

Thus, national, regional and local governments could benefit from the sharing of experiences, information, knowledge and resources with the ultimate end to match both the international and European targets in the matter of sustainable energy.

Ultimately, in Italy, the increase in the number of PV plants and installed power (Figure 1.2) was the combined result of proper mechanisms (*e.g.* FIT scheme), tools, and governance approaches together with the recognition of the even more pressing environmental issues.

The need to address such environmental issues was also made clear with the drawing up of an *ad hoc* action plan, which is presented in the next subsection.

2.2.1. *The Italian national renewable energy action plan.*

The Italian national renewable energy action plan (NREAP) was drawn up in accordance with the requirements of the Directive 2009/28/EC[78] and it was notified to the European Commission in July 2010.

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[76] The 2020 package is a set of binding legislation to ensure the EU meets its climate and energy targets for the year 2020. The three targets fixed are the following: 20% cut in GHG emissions (from 1990 levels), 20% of EU energy from RES$_s$ and finally 20% improvement in energy efficiency. For more details, see *http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm*.

[77] Notably, “public interest in climate change emerged initially through international and national science-policy interactions, however it has become increasingly evident that regional and local decisions are essential in the design and implementation of mitigation and adaptation strategies to respond” (Corfee-Morlot *et al.*, 2009). Multi-level governance approach provides a framework, which helps to better understand the relationships – both horizontally and vertically – between local, regional, and national governments (Bulkeley & Betsill, 2005; Betsill & Bulkeley, 2006).

[78] The Directive 2009/28/EC aims at “establishing a common framework for the promotion of energy from renewable sources. It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport” (Directive 2009/28/EC, art.1, available: *http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=IT*).

In line with a multi-level governance approach, the NREAP aimed at promoting the production of clean energy from RES$_s$ by involving public organizations belonging to the different levels of government.

The strategic guidelines of the Italian national energy policy – set out in the NREAP – might give rise to four major layers of a hypothetical pyramid made up, going from the bottom to the top layer, as follows: *principles*, *mechanisms*, *targets*, and *objectives*.

The lowest layer, constituting the "theoretical ground or level", would embody the basic ***principles*** that should guide the effective implementation of actions, initiatives, or other measures at the different levels of government. Moreover, such principles should act as "driving forces" raising the need or awareness for continuous improvements by public organizations in the matter of sustainable energy.

The main principles – taken over from an analysis of the NREAP – are the following ones:

- energy efficiency;
- transparency;
- compliance;
- public awareness on climate change and its adverse impacts;
- involvement and collaboration among public administrations at various levels of government (*i.e.*, the national, regional, and local ones).

Notably, the principle of collaboration, which constitutes the basis of the multi-level governance approach, is emphasized in different sections of the NREAP although it seems there is not clear evidence about the way through which such a principle should be really put into practice.

Indeed, it seems that the national legislator wanted to emphasize the relevance of such a principle leaving public organizations free to choose the best way for interacting each other.

Furthermore, the analysis of the NREAP would point out that the principle of collaboration would mainly refer to the vertical relationships among the various tiers of government, while horizontal relationships among public administrations belonging to the same level of government seem to be neglected.

As for the second layer of such a hypothetical pyramid, it would include all those ***mechanisms*** *alias* "operational measures" deemed effective in order to achieve the overall objectives as set by the national energy policy.

The NREAP has provided a comprehensive overview of the priority measures laid down for each of its three areas of intervention *i.e.* the electricity, transport and heating (or cooling) ones.

As far as the electricity sector is concerned, the NREAP has envisaged a specific set of measures for solar PV technology, which may be classified as follows:

- direct measures having financial nature;
- direct measures not having financial nature;
- and finally crosscutting measures addressed to the electricity sector and the two other areas of intervention *i.e.* transport and heating ones.

The first measures included different types of financial incentive mechanisms (*e.g.*, FIT scheme, and net metering mechanism) provided by the national government to public organizations (as well as to private ones) in case of PV installations on their buildings.

The NREAP also envisaged the introduction of capital subsidies (*alias* "*bandi in conto capitale*") aimed at financing, for instance, the installation of PV plants on public buildings in order to foster clean energy production.

At national level, another outstanding programme – known as "*the Sun in the public buildings*" – was launched to encourage the installation of solar PV plants by adopting the third-party financing (TPF) mechanism[79] in place of the conventional direct financial aids.

Beside the above measures, the NREAP has also introduced "direct measures not having financial nature" including, for instance, processes of electrical grid modernization and expansion, especially in Southern regions of Italy, in order to allow public organizations (and private ones) an easier access to the electrical grid in case of grid-connected solar PV systems.

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[79] The "third-party financing" is a "contractual arrangement involving a third party – in addition to the energy supplier and the beneficiary of the energy efficiency improvement measure – that provides the capital for that measure and charges the beneficiary a fee equivalent to a part of the energy savings achieved as a result of the energy efficiency improvement measure" (Directive 2006/32/EC, art. 3, k letter; available: *http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006L0032&from=FR*).

Finally, among the heterogeneous set of "crosscutting measures", one might mention the introduction of more simplified authorization procedures[80], international initiatives to enhance the cooperation with EU and non-EU countries, research and development programmes, public awareness and campaigns on sustainable energy issues, and further incentive mechanisms (*e.g.* Kyoto Rotation Fund).

Through the setting of the above crosscutting measures, the national legislator made clear the need for a multi-sectorial approach in order to promote a greater adoption and deployment of the solar PV technology.

However, among the wide set of measures, the plan recognized the effectiveness of financial aids in supporting the adoption of PVs by reporting as follows: "*incentive mechanisms have demonstrated to be able to sustain a steady growth of the electricity sector and [....] they should be an important element of continuity for achieving the European Union's new targets*" (NREAP, 2010: 7).

Indeed, the introduction of financial incentive mechanisms was needed to endow public organizations with proper resources in order to strive towards specific targets.

As regards the ***targets***, the NREAP included two binding commitments aimed at attaining:

- 17% of energy from renewable energy in gross final consumption of energy in 2020;
- 10% of RES$_s$ in final consumption of transport sector in 2020.

In comparison to other EU countries' targets, the first mandatory target is not excessively high if one takes into account the highest target assigned to Sweden (*i.e.* 49%) and the lowest one attributed to Malta (*i.e.* 10%).

Beside the above mandatory targets, the NREAP added two other non-binding targets – to be achieved by means of RES$_s$ – regarding the "electricity" and the "heating" sectors equal to 26.4% and 17.1%, respectively.

Although not mandatory, the higher electricity target (26.4%) than the mandatory one set for the overall Italian energy sector (*i.e.* 17%) would confirm the greater "burden" that the electricity sector would have in comparison to other ones.

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[80] Such an issue is better discussed in Section 2.4.1.

That is due to the larger electricity consumptions that, in turn, lead to huge CO_2 emissions released into the atmosphere.

For such reasons, it is extremely likely that the Italian national legislator aimed at making explicit its commitment specifically for the electricity sector with the ultimate end to increase energy efficiency[81] and, then, to reduce anthropogenic GHG concentrations.

Moreover, the national target of 26.4% for the electricity sector was further split into smaller sub-targets for each single year (from 2010 to 2020) for purposes of monitoring.

However, two main points were not made explicit, namely:

- the contribution of public organizations to the achievement of the national target of 26.4%;
- the contribution of each technology based on RES_s (*e.g.* solar PV, and hydropower) in reaching the electricity target. As for the solar PV technology, some estimations were formulated according to which the installed PV power would be more than tripled in just 10 years by ranging from 2,500 MW in 2010 to 8,000 MW in 2020.

Finally, basic principles, operational measures and targets should converge towards the achievement of the overall ***objectives***[82], which, in turn, might be distinguished as follows:

- *micro-objectives* including energy consumption reductions, energy supply security, and promotion of innovative technological chains;
- *meso-objectives* embodying the reduction of CO_2 emissions and, then, environmental protection;
- *macro-objective* represented by the main outcome of the national energy programme *i.e.* the pursuit of a “sustainable energy development”.

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[81] Energy efficiency is defined as “a way of managing and restraining the growth in energy consumption. Something is more energy efficient if it delivers more services for the same energy input or the same services for less energy input”. See International Energy Agency website *http://www.iea.org/topics/energyefficiency/.*

[82] The main difference between targets and objectives lies in their different nature since targets would have quantitative character (as they are usually expressed in percentage) while objectives would be featured by qualitative nature. Thus, targets and objectives would tend to measure the growth and development of RESs.

The implementation of an effective monitoring system is required in order to evaluate the extent to which targets and objectives are achieved.

In Italy, the entity in charge of statistically monitoring the energy efficiency level is the GSE, which monitors – on a periodic basis – the following shares:

- the national actual share of renewable energy regarding the overall three areas of intervention *i.e.* electricity, heating, and transport ones;
- the national actual share of renewable energy related to the electricity sector;
- finally, the regional actual share of renewable energy for the electricity sector.

The monitoring activity takes place by comparing the actual shares to the target ones in order to identify possible gaps and, then, to provide ongoing and *ex post facto* corrective actions.

Ultimately, the analysis of the NREAP would reveal some analogies with the schematic model of the "core control system" proposed by Flamholtz who identified an integrated structure of four basic processes: planning, operations, measurement, and evaluation-rewards ones (1983).

As already discussed, the NREAP would envisage a planning process with the identification of mandatory and non-mandatory targets as well as strategic objectives.

There are also sections devoted to the identification of effective mechanisms and actions to be implemented in order to achieve the desired objectives.

Finally, the activity carried out by the GSE – aimed at identifying potential gaps between the targets and actual results – would present some analogies with the measurement process.

However, unlike the model proposed by Flamholtz, the NREAP would not include any reward system although the introduction of rewards might contribute to stimulate public administrations in adopting strategies and actions addressed towards the achievement of a sustainable energy development.

2.3. THE LEADING ROLE OF PUBLIC ORGANIZATIONS FOR UNLEASHING ENERGY EFFICIENCY: FOCUS ON PHOTOVOLTAIC TECHNOLOGY.

Italian public organizations can play a crucial role in improving energy end-use efficiency in order to limit CO_2 emissions and, thereby, mitigating harmful climate changes[83].

They would represent an important "driver" to meet mandatory and non-mandatory targets set at both the European and Italian national levels in the matter of sustainable energy, as introduced earlier (Satterthwaite, 2006).

In addition, one may identify other reasons for which energy efficiency issues would require a strong participation and involvement of public organizations at different levels of government (*i.e.* local, regional, and national ones).

Firstly, public organizations should endeavor to ensure the overall community well-being in terms of environmental quality, social welfare, and economic growth according to a "multi-dimensional" or "integral sustainable development" approach (Sorci, 2005; Kapur Bakshi, 2012).

Indeed, energy efficiency projects – implemented in the public sector – may yield outstanding benefits to the overall community (*e.g.,* better life quality), especially over a long-time horizon (Payne *et al*., 2015).

Based on this, public organizations are expected to take an active role in investing in PV systems since these latter can generate significant benefits to the organizations themselves as well as to the whole community[84].

Secondly, the achievement of energy efficiency targets by public organizations may represent a good example for citizens, who may decide to actively contribute in limiting CO_2 emissions by undertaking energy efficiency actions, as well.

Therefore, thanks to the active role of public organizations, it is extremely likely that a "*multiplier effect*" would take place as a result of the involvement of citizens

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[83] Note that several community level regulatory instruments (*e.g.*, the energy services, the recast energy performance of buildings and the new energy efficiency directives) emphasize the role of Member States of the EU in ensuring that the public sector organizations fulfil an exemplary role in energy end-use efficiency (Czako, 2013).

[84] Indeed, the effectiveness of actions should be assessed by taking proper "lenses", which allow to considering not only the effects that such actions might produce over the single organization where such actions have been undertaken but also taking into account the wider system or local area where the organization itself is embodied.

in the pursuit of a sustainable energy development. Here, local governments may play a crucial role. Indeed, it is “within the powers of local government to influence the energy choices of their citizens” (IEA/OECD, 2009).

Moreover, public organizations – that actively contribute to the achievement of energy efficiency targets – may stimulate the adoption of PVs by other public organizations not initially involved.

In particular, this can be made possible through the “benchmark of excellence”, an effective tool through which “active” public organizations might fulfill their role of promoters by sharing information, experiences, and best practices at all levels of government.

Based on the above premises, the crucial role of public organizations in unleashing energy efficiency actions would depend on their aptitude to potentially take a triple role *i.e*. the role of “*investors*”, “*users*”, and “*promoters*” of sustainable energy.

As for the PV systems, Italian public organizations have played all the three above-mentioned roles since:

- they have invested financial resources in PV systems;
- they have used the generated clean energy for meeting their electricity needs thus contributing to improve their energy efficiency standards;
- and they have encouraged other public organizations in adopting PV systems, as well. In particular, such a role of promoters has been mainly fulfilled by local governments[85].

Finally, one may come to the following conclusions:

- solar PV systems have been mainly installed on public buildings;
- solar PV systems have been mainly adopted at a local level of government (*i.e*. municipalities).

More details about the above key points are provided in the next subsection.

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[85] Today, due to the increasingly active network of local organizations “a consensus is emerging that the notion of “think global-act local” remains imperative to find sustainable solutions” (Mans, 2012).

2.3.1. *Energy efficiency actions in the public sector: the "Sun" in public buildings.*

Over the last twenty-thirty years, legislators – at both European and Italian national levels – paid particular attention to energy efficiency issues of public buildings[86].

In more recent times, the European legislator envisaged as follows: "*national energy efficiency plans should set more ambitious targets for the buildings occupied by public authorities*" (Directive 2010/31/EU), thus emphasizing the need for energy efficiency improvements.

In the Italian context, one may identify two major reasons why public buildings would require interventions to improve their energy efficiency standards.

Firstly, according to a recent study[87], there are almost 2,6 million buildings featured by poor energy performance.

A large share of such buildings is owned by public organizations, in particular by local authorities that altogether own over 60% of the total public real estate[88] (Frigo, 2014). That is why local public organizations are expected to take an active role in implementing energy efficiency measures in order to contribute to environmental protection.

Secondly, such public buildings are responsible for high-energy consumptions that unavoidably contribute to raise the rate of CO_2 emissions released into the atmosphere.

Over the last decades, in order to promote energy efficiency actions for public buildings, Italy launched three important energy-environmental programmes concerning the installation and use of solar PV systems (Tedesco, 2010: 28):

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[86] As far as the European Union level is concerned, one might mention the Directive 93/76/EEC, Directive 2002/91/EC, Directive 2006/32/EC, Directive 2010/31/EU as well as Directive 2012/27/EU. As regards the Italian level, one might mention law no. 373/76, law no. 10/91, legislative decree no. 192/2005, and legislative decree 311/2006.

[87] Nomisma, *Traiettorie per lo sviluppo di una Grey Economy nella Pubblica Amministrazione*, September 2012.

[88] Note that, the Directive 2012/27/EU also came to a similar conclusion by reporting as follows: "*buildings owned by public bodies account for a considerable share of the building stock and have high visibility in public life. It is therefore appropriate to set an annual rate of renovation of buildings to upgrade their energy performance*". Available at: *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:en:PDF.*

- the "*Photovoltaic Roofs National Programme*"[89] aimed at furthering the installation of PV systems – with a power ranging from 1 to 20 kWp – on buildings connected to the national electrical grid. Such a programme also included other sub-programmes just for public organizations or, alternatively, for both public and private organizations;
- the "*National Programme for promoting Solar Energy*" aimed at promoting both the installation of PV systems on public school buildings and the implementation of energy efficiency actions in any other public building. In particular, such projects – envisaging the installation of big PV integrated panels with a power ranging from 1 to 50 kWp – were implemented thanks to government financial aids equal to 2,6 million euro;
- the programme "*Schools for Kyoto*" aimed at reducing energy consumptions in school buildings, promoting the use of solar PV systems and raising students' awareness on environmental and energy efficiency issues[90].

As for the installation of PV plants on public school buildings, an ambitious project was the one launched by the Province of Rome in 2009[91].

Indeed, such a project envisaged the installation of solar PV plants on almost all public school buildings owned by the Province of Rome (around 301 buildings) in order to generate electricity for meeting schools' energy demand, to limit CO_2 emissions, and to further the use of technologies based on RES_s.

The project was defined "ambitious" for its potential environmental, financial, and social benefits, *i.e.*:

- potential reduction of CO_2 emissions equals to 55,000 tons over a period of 30 years;
- average yearly production of clean energy from PV plants equals to 3, 7 MWh;

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[89] This programme was supported by the "Italian National Agency for new technologies, energy and sustainable economic development" (ENEA - Agenzia Nazionale per le nuove technologie, l'energia e lo sviluppo economico sostenibile). Moreover, the programme was operative during the period 2001-2002 and 2003-2004.

[90] See *https://www.kyotoclub.org/index.php?go=98a.*

[91] See "*Impianti fotovoltaici in partenariato pubblico privato manuale operativo*" (Camera di Commercio di Roma), February 2012.

- involvement of the private sector[92] to finance the total cost of the PV investments (equals to around €22 million);
- higher students' awareness of environment, global warming and other issues concerning energy efficiency.

The ambitious programme undertaken by the Province of Rome is an example showing how public organizations may contribute in promoting energy efficiency actions through the production of clean energy.

2.4. BUREAUCRATIC, SOCIAL, AND FINANCIAL ISSUES AFFECTING THE ADOPTION OF PV SYSTEMS.

In this section, the focus is on the main bureaucratic, social, and financial issues that may have some kind of influence – either positive or negative – on the adoption of PV systems in the public sector and, then, on the production of clean energy.

To this end, the first subsection introduces the European and Italian regulations envisaging more streamlined and simplified bureaucratic procedures.

The second subsection discusses the social acceptance of technologies based on the use of RES_s.

Finally, the third subsection outlines the main financial incentive public policies for PVs as well as the potential financial barriers that may affect a wider deployment of PV systems in upcoming years.

2.4.1. *Towards more simplified bureaucratic procedures*.

A successful deployment of PV systems requires streamlined bureaucratic procedures, clear legal frameworks, and simplified authorization procedures (Pozzo, 2009; Garbe *et al.*, 2012).

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[92] See Hughes, 2012.

Indeed, bureaucratic red tape may delay the installation of PV systems or compromise their full operation[93] with implications on the production of clean energy.

In order to increase electricity production from RES$_S$, the directive 2001/77/EC[94] recommended to each Member State the reduction of their regulatory and non-regulatory barriers (art. 6).

In December 2003, Italy adopted such a directive with the legislative decree no. 387/2003, which introduced the "unique authorization"[95] with a view to streamlining authorization procedures for plants powered by renewable energy sources (art. 12).

Nevertheless, the "unique authorization" seemed to have fallen short of expectations mainly due to the lack of national guidelines, which triggered a proliferation of different regional regulations[96] (Falcione *et al.*, 2010). Thus, for instance, the time needed for obtaining the authorization ranged from a couple of months in some regions (*e.g.*, Lombardy) to more than one year in other ones (*e.g.*, Sicily)[97].

Such a situation started changing since 2010 thanks to the premises included in the Italian national renewable energy action plan[98], the setting of national guidelines

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[93] Note that bureaucratic red tape may take place before and after the installation of PV plants. In the last case, bureaucratic red tape can be related, for instance, to procedures needed to carry out PV maintenance operations.

[94] It is the Directive of the European Parliament and of the Council on the "*promotion of electricity produced from renewable energy sources in the internal electricity market*".

[95] The "unique authorization" is issued at the end of a *unique procedure* in which any interested authorities take part to the so-called "Conference of Services". Notably, the main task of the Conference of Services is to acquire permissions through the involvement of all the bodies involved (GSE, 2011). The authorization is issued by Regions or delegated Provinces. The "unique authorization" can be required when certain thresholds of installed power are overcome. For solar PV technology, such threshold is set at 20 kW of installed power (*ex*-legislative decree no. 387/2003).

[96] Moreover, the lack of national guidelines i.e. the lack of a harmonized legal framework led to further consequences such as, for instance, long delays in the authorization process, and lack of coordination between different authorities (Pietruszko *et al.*, 2008; Assosolare, 2011).

[97] Such a fragmentation could have been furthered by the Reform of Title V of the Italian Constitution (Constitutional Law no. 3/2001), which re-distributed competences between the State and the Regions in view of the decentralization process, also in the matter of energy (OECD, 2009; Mangiameli, 2014).

[98] In particular, the Italian national renewable energy action plan emphasized the need to reduce the complexity of the Italian legislative framework in the matter of "Energy" and "Authorizations".

for the unique authorization[99] and the legislative decree 28/2011[100], which laid down the foundations for a more harmonized legal framework and more simplified authorization procedures.

In particular, the legislative decree 28/2011 set a shorter deadline – equals to 90 days – for completing the authorization procedure in comparison to the one initially introduced with the legislative decree no. 387/2003, which was equal to 180 days (Bruno, 2011).

Therefore, such a shorter deadline may allow public organizations to obtain the needed authorizations in less time thus making possible a faster completion of their PV projects.

Beside the unique authorization, more simplified procedures were also introduced for the "landscape authorization"[101] with the legislative decree no. 63/2008 and the decree of the President of the Republic no. 139/2010, which modified the "Code of Cultural Heritage and Landscape" (legislative decree no. 42/2004)[102].

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[99] The National Guidelines for Unique Authorization were introduced in 2010 (ministerial decree 10/09/2010) in order to regulate the administrative procedures for the unique authorization (Arecco *et al*., 2011). Thus, these national guidelines saw the light in the late 2010 although announced seven years before in the legislative decree no. 387/2003.

[100] The legislative decree 28/2011 explicitly laid down as follows: "*the construction of plants producing energy from renewable sources are regulated according special administrative procedures that are simplified, accelerated, proportionate and appropriate and based on the specific characteristics of each individual application*" (art. 4). Based on this, Italy adopted the European directive for the promotion of renewable energy (Directive 2009/28/EC), which envisaged provisions for the simplification of administrative procedures.

[101] According to art. 146(2) of legislative decree 42/2004, the proprietors, possessors or holders by whatever legal right of immovable property and areas of landscape values "*shall be obligated to submit the plans of the works they intend to carry out, accompanied by the required documentation, to the Region or local body to which the Region has delegated the relative competence*". When the request for authorization provided under article 146 concerns works to be carried out by State administrations, the authorization shall be issued following a conference of services (art. 147 of legislative decree no. 42/2004). The required documentation is defined by the Decree of the President of the Council of Ministers of December 12, 2005. Available: *http://www.gazzettaufficiale.it/eli/id/2006/01/31/06A00800/sg*.

[102] The Code of Cultural Heritage and Landscape (Sandulli, 2012) introduced provisions in line with the principle of the "European Landscape Convention" ratified with the law no. 14/2006 (Mariotti, 2010; Voghera, 2011). The "European Landscape Convention" is the first international convention addressing the protection, management and planning of all landscapes in Europe. It was adopted by the Committee of Ministers of the Council of Europe on 19th July 2000. The practical and regulatory steps taken to protect, manage or plan landscapes should contribute to the achievement of a "sustainable development". The official text of the Convention can be found on the following website:

Although a shorter deadline equals to 60 days has been set for obtaining the landscape authorization, some criticalities may be taken over.

Firstly, the simplified procedure was introduced just for small PV plants (25 m^2 equivalent to almost 3 kW) and, consequently, it may lead to low advantages for public organizations since they usually install medium-large scale PV power plants.

Moreover, in Italy, there is a large number of areas subject to landscape restrictions[103] and, therefore, the likelihood that PV projects fall into such areas may be quite high with the subsequent risk that the landscape authorization may be denied.

Notably, the last point calls for another issue that is the potential dilemma “landscape *vs*. environmental protection”. Indeed, there is the need to balance the landscape preservation on the one hand and the reduction of CO_2 emissions through the production of clean energy on the other.

In some cases, an excessive focus on landscape protection may translate into a lower social acceptance of technologies based on RES_s. Such an issue is discussed in the next subsection.

2.4.2. *Social acceptance of renewable energy technology: focus on “Nimby and Nimto” phenomena.*

Wüstenhagen, Wolsink, and Bürer (2007) proposed the “*triangle of social acceptance of renewable energy innovation*”, by identifying three levels of acceptance *i.e*. the socio-political, community, and market ones.

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https://rm.coe.int/CoERMPublicCommonSearchServices/DisplayDCTMContent?documentId=09000016802f80c6.

[103] See *http://www.sitap.beniculturali.it/*.

Figure 2.4. The triangle of social acceptance of renewable energy innovation (Source: Wüstenhagen *et al*., 2007, p. 2684).

Socio-political acceptance represents the broadest level in which both policies and technologies can be subject to societal acceptance by the public, key stakeholders, and policy-makers (Carlman, 1984).

Community acceptance refers to the social acceptance – of renewable energy technologies in specific geographic areas – by local stakeholders (*e.g.*, residents and local authorities).

Finally, *market acceptance* focuses on an individual level of acceptance of renewable energy technologies, which is made explicit through, for instance, investment behaviors[104].

In Italy, some resistance to public work projects has been observed at the *community level*, where the debate around the NIMBY (Not in My Backyard)[105] syndrome unfolded[106].

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[104] The present research focuses on the socio-political acceptance, although the other two points of triangle are of equal importance.

[105] The use of "Nimby" term dates back only to 1980, when it appeared in the *Christian Science Monitor* article. See *http://www.psandman.com/col/nimby.htm*. Now, "the term is applied to indicate a situation where a significant number of people in a local social, geographic area opposes an event or new development projects in their neighbourhood or community" (Barton-Bellessa, 2012: 260). In principle, the opposition or resistance by a local community would concern the siting of a given plant or infrastructure and not its implementation *tout court* (Occhilupo *et al*., 2012).

[106] Note that opposition of local communities to new projects may also be described by acronyms such as, for instance, LULU (Locally Unwanted Land Uses), NOOS (Not On Our Street), NIABY

An analysis of the main NIMBY Forum Reports[107] reveals how, over the last years, the NIMBY phenomenon has witnessed two relevant changes.

The first one concerns the "objective sphere" since a growing number of local protests has strikingly challenged even energy plants fueled by RES_s such as, for instance, solar PV systems, biomass plants, wind farms, and hydropower plants.

Local protests have been mainly fed by the fear that potential damages to the landscapes may arise from the adoption of renewable energy technologies (Nimby Forum Report 2011).

For instance, solar PV plants, especially the ground-mounted ones, have been criticized for having a strong visual impact and for being not compatible with other types of land use (Frolova *et al.*, 2015). Indeed, "when PV ground-mounted plants are sited in previously cultivated areas, they lead to a change in land use (Prados, 2010) and a reduction in the potentially cultivable land area" (Tsoutsos *et al*., 2005).

The second relevant change – falling under the "subjective sphere" – refers to the parties involved in such protests that, today, see a growing participation of the *socio-political level*, as well.

Indeed, in 2013, politicians and public authorities have supported 48.5% of total protests and their active role has been confirmed in the last two Nimby Forum Reports, as well (2014, 2015).

In particular, these parties involved would tend to adopt the so-called NIMTO (Not In My Term of Office) logic, which "consists of an attitude of opposition, or at least in the aim to delay the establishment of a controversial infrastructure during one's own electoral mandate, without any assessment of the related public interest" (Peeters & Schomerus, 2014: 306)[108].

(Not In Any Back Yard), NOTPE (Not On The Planet Earth) and BANANA (Build Absolutely Nothing Anywhere Near Anyone). See Pizzanelli, 2010: 102-103.

[107] Nimby Forum is a research project on the phenomenon of territorial disputes handled by the non-profit "Aris - Agenzia di Ricerche Informazione e Società" in Italy. Now, it constitutes the first and only national database of public works experiencing disputes and is acknowledged as an important think tank on the subject. See *http://www.nimbyforum.it/home*. Nimby Forum Reports can be found on the following webpage: *http://www.nimbyforum.it/area-stampa/comunicati*.

[108] Therefore, the NIMBY phenomenon relates to the second level of social acceptance (*i.e.* the community level) whereas the NIMTO logic refers the broadest level of social acceptance (*i.e.* the socio-political level) of the triangle portrayed in Figure 2.4.

Based on this, some consequences may follow. Firstly, there may be the risk that local politicians may neglect the overall public interest by discouraging, for instance, the shift towards environmentally friendly energy sources.

Secondly, there may be an increasing gap between the theoretical support to green technologies on the one hand and the NIMTO/NIMBY actions on the other.

Therefore, in order to avoid the risk that the lack of social acceptance – at different levels – hampers the adoption of RES$_s$ (*e.g.*, PV systems), it is important that all involved parties change their own approaches.

Community involvement in planning and implementation of energy action plans may lead to a greater social acceptance. That means "raising community concerns for discussion, listening and constructively responding to potential alternatives, and contributing to a process by which agreeable solutions are reached" (Rogers, 1998: 279). Participation and open decision-making processes might be instrumental to support environmentally respectful planning (Vigar & Healey, 2002; Wolsink 2007).

Communication and information about potential benefits associated with the adoption of renewable energy technologies may contribute to enhance their social acceptance at the community level.

As for the socio-political level, local politicians shall properly translate national objectives into locally accepted policies in order to prevent local resistance to renewable energy-based projects.

For instance, they shall take into account both the needs for landscape preservation and the socio-environmental benefits associated with the adoption of solar PV plants by looking for a good balance between these two factors.

Finally, they shall look beyond the short-term horizon even if it might be politically unrewarding since PV projects might entail high short-term costs but large benefits over a longer time span.

2.4.3. *Identification of the main financial issues.*

The Italian PV market has been characterized by very high purchase costs (IEA, 2013) and, consequently, the prices of PV modules have been higher than the ones recorded in other EU countries (Di Dio *et al*., 2015).

To support the growth of the Italian PV sector, some incentive policies were introduced.

The first Italian incentive policy, known as "10,000 PV Roofs", was launched in 2001, which introduced capital subsidies – equal to 60-70% of the total purchase, installation, and design costs – for PV systems with a rated power up to 20 kW.

Moreover, as previously anticipated, in 2003, Italy introduced one of the most common incentive mechanisms adopted in many EU countries *i.e*. the feed-in tariff (FIT)[109] scheme (Campoccia *et al*., 2009). It was introduced with the legislative decree no. 387/2003 and became operative two years later.

In particular, the value of tariffs depended on the installed PV capacity, the generated energy and the type of PV plants[110].

Such a mechanism – that was established to encourage the uptake of solar PV technology – witnessed some changes throughout the years; in particular, five versions[111] were issued from 2005 to 2013[112].

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[109] The value of a FIT "represents the full price received by an independent producer for any kWh of electric energy produced by a PV system (Favuzza & Zizzo, 2011: 2667).

[110] Indeed, distinct tariffs were set for the following types of PV plants: not-integrated in building PV plants (NIPV); partially integrated in building PV plants (PIPV); building integrated PV plants (BIPV); innovative building integrated PV plants (IBIPV); in building PV plants (IBPV); concentrated PV plants (CPV) and finally other PV plants (OPV). For more details, see Di Dio *et al.,* 2015: 99.

[111] The first FIT scheme came into force in 2005 with two successive ministerial decrees (M.D. of 28 July 2005 and M.D. of 6 February 2006). The second FIT scheme entered into force with the M.D. of 19 February 2007. As for the third FIT scheme, it was operative for a very short period *i.e.* from 1st January 2011 to 31st May 2011 and it was introduced with the M.D. of 6 August 2010. Finally, the fourth and fifth version of FIT scheme were introduced with the M.D. of 5 May 2011 and the M.D. of 5 July 2012. For these last two, see *http://www.gse.it/en/feedintariff/Photovoltaic/Pages/default.aspx*.

[112] In particular, by moving from the first FIT scheme to the last one, it is possible to take over as follows: 1) a greater degree of detail (as to complexity) in setting the rules and procedures for accessing to the scheme; 2) continuous changes regarding the granting of additional premiums (or more favorable financial conditions) with the risk to disseminate uncertainty for PV investors; 3) unstable legislative framework that led to changes in defining the strategies for PV systems; 4) pressure or rush for completing the installation of PV plants especially during the time of the fourth and fifth FIT schemes when the related tariffs were time-decreasing *i.e.* depending on the date of connection of the PV plant to the grid.

In 2013, the FIT scheme definitively ceased to be applied.

Therefore, today, public organizations might run the risk to cope with some financial difficulties that may affect the adoption of PV systems.

In particular, the lack of FIT scheme may reduce the inclination of private organizations to financially support the adoption of PV systems in the public sector[113] since they cannot rely anymore on incentive tariffs, unless other favorable conditions are set to compensate the lack of the tariffs.

In other cases, financial difficulties for public organizations may arise as a result of the combined effect of the lack of FIT schemes together with other factors, *i.e.*:

- absence of other incentive mechanisms for PVs having a similar role of the traditional FITs[114];
- shortage of public organizations' financial resources, which may especially hinder the adoption of large scale PV power plants because of the huge amount of money needed;
- difficulties in applying for a mortgage to finance PV investments, which may be exacerbated by the "internal stability pact". Indeed, this latter often implies a lower budgetary autonomy on the capital outlays of public organizations (PVs in bloom, 2011; Ruffini, 2014).

Therefore, financial difficulties might become a "straightjacket" for public organizations since they are expected to take an active role as "investors", "users", and "promoters" of renewable energy technologies, even in the current context characterized by the absence of FITs.

In order to understand to what extent the FIT scheme has contributed to foster the adoption of PV systems in the public sector, the next section provides the trend of PV power installed before and after the end of the FIT scheme.

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[113] Indeed, the participation of private organizations – though the so-called "Public-Private Partnership" (PPP) – has represented one of the most schemes adopted by public administrations as regards PV investments. In particular, PPP can be defined as "*a long term agreement between the government and a private partner where the service delivery objectives of the government are aligned with the profit objectives of the private partner*" (OECD, 2008: 17).See: *http://www.rm.camcom.it/moduli/downloadFile.php?file=oggetto_pubblicazioni/153221603320O__OI_FOTOVOLTAICI_manuale.pdf*.

[114] Note that GSE has envisaged other mechanisms although having a different nature than the conventional FIT scheme. For instance, GSE has offered simplified "purchase & resale arrangements" to producers who sell the electricity generated and injected into the grid. However, the access to such a mechanism is subject to certain limitations.

2.5. DEPLOYMENT OF PHOTOVOLTAICS IN THE PUBLIC SECTOR.

In Italy, the growth of the PV sector has been mainly driven by the secondary sector (GSE, 2014).

Over the last years, the tertiary sector has also provided its contribution to the growth of the PV sector. Indeed, the PV power installed in the tertiary sector has increased very strongly, more than doubling in just four years by going from 11% in 2010 to 24% in 2014[115].

However, such a growth does not necessarily imply that a large contribution comes from public organizations since, by definition, the tertiary sector includes services provided by both private and public organizations.

Figure 2.5 shows the trend of PV power installed in the Italian public sector from 2010 to 2015[116].

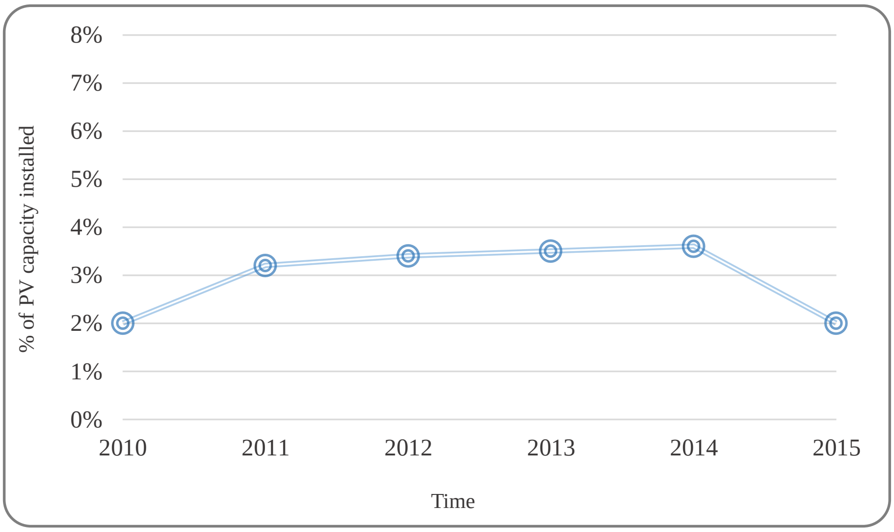

Figure 2.5. Trend of PV power installed in the Italian public sector (Source: Elaboration of GSE data).

As Figure 2.5 shows, the most significant increase in the installed PV power has occurred between 2010 and 2011.

From 2011 to 2014, the PV power has increased at a decreasing rate by ranging from 3.2% to 3.6%, respectively.

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[115] See “GSE Rapporto Statistico” from 2010 to 2014.
[116] See “GSE Rapporto Statistico” from 2010 to 2015.

In particular, from the year when the FIT schemes ceased to be applied *i.e*. 2013 to 2014, the growth rate of the installed PV power was equal to +0.02%.

In 2015, the situation got worse since public organizations installed lower PV power in comparison to the previous four years, that is just 2% (corresponding to 660 MW) of the total PV power installed in Italy while the number of the PV plants was equal to 13,614 (*i.e*. 3.5% of the total number of PV plants).

Figure 2.6 illustrates the local deployment of PV plants – owned by Italian public organizations – at the end of 2015.

Figure 2.6. Local deployment of PV plants owned by Italian public organizations in 2015 (Source: GSE, 2015, p.51).

As Figure 2.6 shows, in 2015 the deployment of PV plants in the public sector was nearly homogenous across the Italian regions[117]. Almost 60% of Italian local governments owns at least one PV plant.

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[117] The top ten municipalities for the highest share of installed PV power are located in the North of Italy (*e.g*., Verona, Cisano Bergamasco, Bologna, Milan, Bergamo, Cerano, Gorizia, Ferrara, and Villa Guardia). See Legambiente Report, 2015.

However, it is not only important the number of PV plants owned by public organizations but also the installed PV power, which indicates how much green energy PV plants are able to generate.

Today, there is indeed the need to improve the performance of the PV sector since in 2015, as already shown, the growth rate of the PV power installed in the public sector was equal to -0.44% (Figure 2.5).

Based on this, the next Chapter introduces the performance management systems in order to understand how such systems may contribute in supporting the adoption of PV systems in the public sector.

CHAPTER 3

IMPROVING PERFORMANCE ACCORDING TO A SUSTAINABLE DEVELOPMENT PERSPECTIVE IN PUBLIC ORGANIZATIONS THROUGH "DYNAMIC PERFORMANCE MANAGEMENT"

This chapter deals with the need for designing and applying a methodological framework arising from the combination of System Dynamics methodology with the traditional Performance Management systems. Indeed, the resulting "Dynamic Performance Management" approach can better support public decision-makers in managing performance within the sustainability perspective. The "Dynamic Performance Management" approach is introduced after having presented the main advantages and limitations of conventional Performance Management systems and the main features of System Dynamics. Tools for applying the Dynamic Performance Management approach – borrowed from the System Dynamics methodology – are also presented by providing examples applied to the PV sector. Finally, the contribution of the Dynamic Performance Management approach to the PV sector in public organizations is argued by envisaging two levels of analysis i.e. *the institutional and inter-institutional ones.*

3.1. INTRODUCTION.

In the previous Chapter, it has emerged the need to foster the adoption of PV systems in the public sector with a view to achieving sustainable development in terms of clean energy production. In this regard, one may identify two major "levers" (Bianchi, 2012b), *i.e.*:

- the "***subjective***" lever that refers to the ideas, culture, and vision of public decision-makers, which can be or cannot be sharply oriented towards the pursuit of sustainable development depending on their aptitude to focus on inputs, outputs, or outcomes;
- the "***objective***" lever that relates to the organizational system, which includes *inter alia* the types of performance measurement, management, and rewards systems adopted by public organizations.

By crossing both the two levers, one may obtain a matrix (Figure 3.1) depicting four different situations.

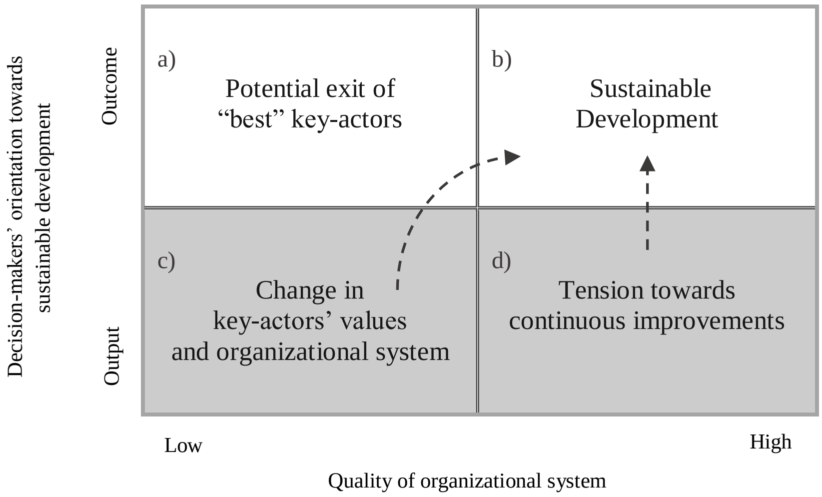

Figure 3.1. Two levers for achieving sustainable development in public sector organizations (Adaptation from Bianchi, 2012b, p. 101).

Notably, both high quality of organizational system and decision-makers’ orientation towards outcomes would steer public organizations towards the achievement of sustainable development in the long term (quadrant b).

However, the outcome orientation by decision-makers would represent a necessary but not sufficient condition for steering public organizations towards paths of sustainable development since a low quality of organizational system may lead to the potential exit of the “best” key-actors involved (quadrant a).

Sustainable development may be potentially achieved if radical changes in values and culture of key-actors as well as investments to improve the quality of organizational system take place (quadrant c).

Finally, organizational system featured by a high quality may support the shift from an output to an outcome orientation by decision-makers with a view to pursuing sustainable development. This may be possible thanks to the aptitude of the organizational system to support continuous improvements of public decision-makers’ strategic learning processes (quadrant d).

Based on the above premises, one may conclude that both high quality of key-actors involved (*i.e.* “subjective lever”) and high quality of organizational system (*i.e.* “objective lever”) represent two important conditions to foster the achievement of sustainable development.

However, since one may not directly act on the subjective lever, now the focus is on the objective one, which indeed – as already seen – may indirectly act also on the subjective lever (quadrant d).

In particular, one wants to understand how the traditional PM systems – that are part of the organizational system – may contribute in supporting the adoption of PV systems in the public sector with a view to pursue sustainable development.

3.2. THE NEED TO FOSTER SUSTAINABLE DEVELOPMENT: FROM A TRADITIONAL "PERFORMANCE MANAGEMENT" SYSTEM TO A "DYNAMIC PERFORMANCE MANAGEMENT" APPROACH.

In this section, the traditional PM systems are introduced to better understand how they may contribute in supporting policy-making and performance evaluation of PV investments, installation, and usage in the public sector. To this end, the main advantages and limitations of such systems are discussed.

In order to overcome the limitations of the traditional PM systems, SD methodology is presented by outlining its major features, strengths and, then, its contribution in dealing with the complexity that characterizes the environment where public decision-makers operate.

Based on the advantages arising from the adoption of SD methodology in the public sector, a DPM methodological approach – resulting from the combination of SD with PM systems – is suggested.

3.2.1. *Performance Management: an introduction.*

Performance Management (PM) represents the core of public administration and has become an integral part of modern governance arrangements (Otley, 1999; Pollitt & Bouckaert, 2004).

According to Amaratunga & Baldry (2002), PM can be defined as “the use of performance measurement[118] information to effect positive change in organizational culture, systems, and processes by:

1. helping to set agreed-upon performance goals;
2. allocating and prioritizing resources;
3. informing managers either confirm or change current policy or programme directions to meet these goals;
4. and sharing results of performance in pursuing those goals”.

In particular, PM can be represented as “both about measurement and management, about information and action” (Bouckaert & Van Dooren, 2002). Its purpose is to “enhance the achievement of agency goals and outcomes for the government” (Management Advisory Committee, 2001: 14).

Moreover, PM has been defined as “the process where steering of the organization takes place through the systematic definition of mission, strategy and objectives of the organization, making these measurable through critical success factors and key performance indicators, in order to be able to take corrective actions to keep the organizations on track” (De Waal, 2007).

Based on the above definitions, one may deduce that PM is a framework that encompasses, either implicitly or explicitly, a wide set of elements such as strategies, goals, resources, actions, results, performance indicators, and responsibilities assigned to each organizational area.

The growing interest towards the design and implementation of PM systems has risen in response to the increasing organizational complexity and turbulent environment (De Waal, 2007) in which public (as to private) organizations had to operate.

Thus, organizations started calling for more complex systems able to provide insights about their performance with the ultimate end to support decision-makers in dealing with organizational changes (Martinez, 1997).

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[118] As part of the overall performance management system, performance measurement can serve a variety of purposes. Behn (2003) identifies eight public managers’ purposes for the measurement of performance *i.e.* “to evaluate”, “to control”, “to budget”, “to motivate”, “to promote”, “to celebrate”, “to learn”, “to improve”. See also March, 1987; Kravchuk & Schack, 1996; Wholey & Newcomer, 1997; Hatry, 1999; de Lancer Julnes, 2008; Marr, 2009; Moynihan & Pandey, 2010; Sanger, 2012.

In this regard, Folan & Browne (2005) traced the evolutionary process of PM, correlating it with the level of complexity (Figure 3.2).

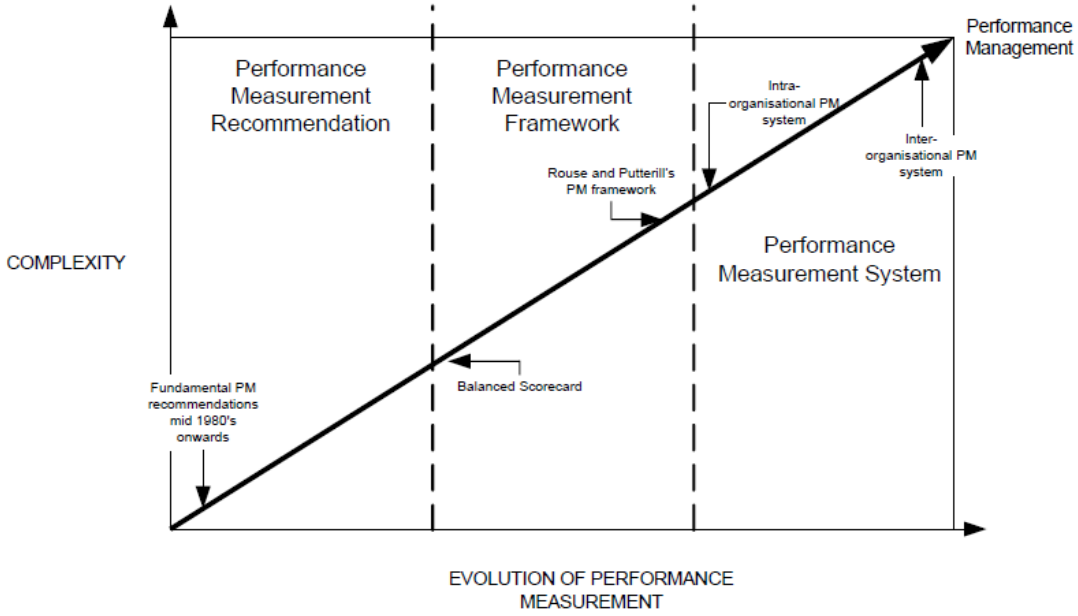

Figure 3.2. The evolutionary process of Performance Management (Source: Folan & Browne, 2005).

As Figure 3.2 shows, PM can be considered the result of a process that started with the formulation of some financially-oriented measurement *recommendations*, continued with the definition of performance measurement *frameworks* (*e.g.*, "Balanced Scorecard")[119] and ended up with the development of more complex performance measurement *systems*[120].

Initially, a narrow focus towards performance measurement[121] (De Bruijn, 2001) was observed *i.e.* when "most governments embraced the mantra "*if you can't measure it, you can't manage it*" (Thomas, 2006: 58).

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[119] See Kaplan & Norton, 1992-1996.

[120] Note that an attempt to set a coherent treatment with regard to PM has been provided by Bouckaert & Halligan (2006), which distinguished between four models of performance: traditional-pre-performance, performance administration, managements of performances and finally performance management. Each model can be applied to the historical evolutionary process of performance management as a useful framework for making possible comparisons between different countries.

[121] A comprehensive definition of "performance measurement would include the regular generation, collection, analysis and reporting of a range of data related to the operation and the impact of public organisations and public programs, including data on inputs, outputs and outcomes" (Thomas, 2006: 10).

Although, performance measurement plays an important role, it is just a single part of the wider performance management system[122]. In particular, there is a loop: performance measurement and performance management follow one other in an iterative process where the second one precedes and follows measurement (Lebas, 1995).

Finally, inter-organizational PM systems will have an "impact outside the organization – in the external environment – the final frontier of PM" (Folan & Browne, 2005). The shift from an intra-organizational PM system to an inter-institutional one is strictly correlated with the increasing level of complexity.

In the public sector, the importance of a PM system lies in its aptitude to pursue a wide range of objectives (Cosenz, 2011: 108), *i.e.*:

- translate mission into strategic objectives and goals;
- communicate and link strategic objectives with performance indicators in order to guarantee consistency between them;
- facilitate the strategic learning processes of public decision-makers;
- use performance information in order to better plan processes and related activities;
- guide organizations towards the desirable changes.

Based on this, PM is relevant for policies of single organizations where policy objectives are interacting with the environment (Figure 3.3).

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[122] See also Carmine Bianchi's Interview on Performance Management in the 2013 "KPI Institute Report" available on the following webpage: *https://www.academia.edu/6234539/My_Interview_on_Performance_Management_in_the_2013_KPI_Institute_Report_.*

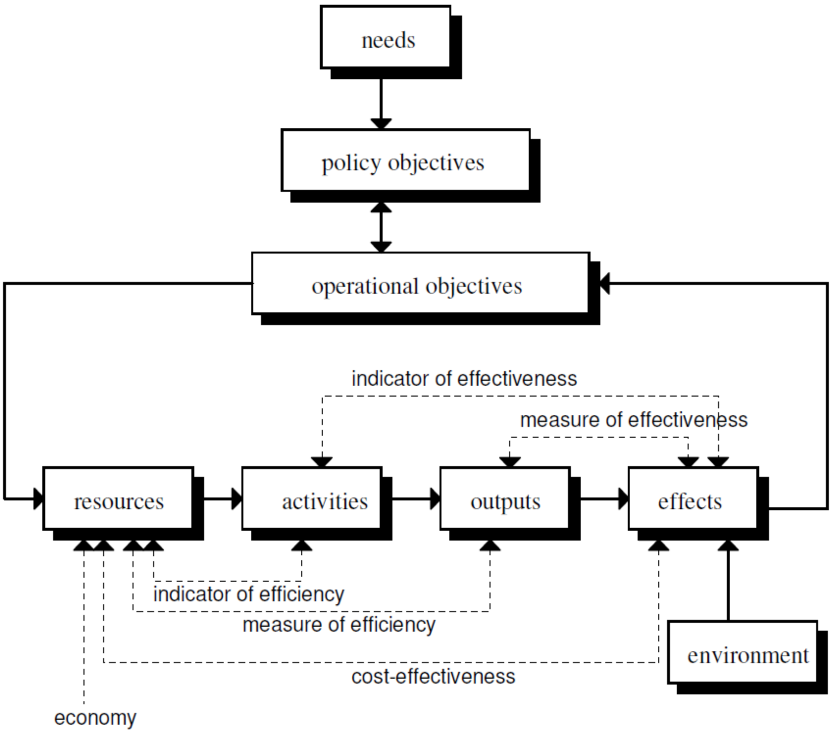

Figure 3.3. Performance Management in a policy context (Source: Bouckaert & Halligan, 2006).

Now, it may be useful to understand whether a PM system has brought added value to public organizations and to what extent its implementation can allow the achievement of objectives within the sustainability perspective.

To this end, the major advantages and critical issues of traditional PM systems are discussed in the next subsection.

3.2.2. *Advantages and criticalities of conventional Performance Management approaches.*

Over the last years, performance literature has addressed issues concerning PM system to understand to what extent it has been successful in practice when implemented in public (and private) organizations.

Kourtit & De Waal (2008) carried out a research study, which aimed at examining the major reasons for use[123] of PM system, its main advantages and criticalities experienced in practice by organizations.

As regards the main advantages, the implementation of a PM system may allow achieving a wide range of benefits.

Firstly, it may foster an *innovation-based perspective* with a view to achieving better results (Sim & Koh, 2001; De Waal, 2002; Brown, 2004; Self, 2004). For instance, through the performance evaluation process, public decision-makers may detect low PV plant performance measured *e.g.* in terms of kWh generated in output of a PV system. The on-going feedback – throughout the PM cycle – may support the turnaround of unsatisfactory PV plant performance by fostering PV investment policies based on more innovative and efficient PV systems able to guarantee a greater clean energy production.

Secondly, a PM system would enable *improvements in work planning* and a better *clarification of individual work tasks* (Lawson *et al*., 2004; Neely *et al*., 2004; Papalexandris *et al*., 2004). That means that each organizational member may gain a better understanding of "who has to handle what" *e.g.* who has to develop a budget proposal for PV investments, who has to draw up PV projects before installation, or who has to provide PV maintenance operations. This, in turn, may positively contribute to achieving better results in terms of less duplication of efforts, less time and resources needed for fulfilling the activities related to the PV projects, the subsequent investments and the usage of PV plants (*e.g.*, less time or human resources needed to carry out PV maintenance operations).

Moreover, the fulfillment of the above activities may benefit from a *higher motivation and involvement of organizational members*, which represent other advantages associated with the implementation of a PM system (Malina & Selto, 2001; Shulver & Antarkar, 2001; Sim & Koh, 2001; Papalexandris *et al*., 2004; Robinson, 2004; Lawson *et al*., 2005).

In addition, the implementation of a PM system may yield *improvements in decision-makers' accountability*, both inside and outside the organization (Lovell *et al*., 2002; Baraldi & Monolo, 2004; Heras, 2004; Lawson *et al*., 2004) and,

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[123] Major reasons for use of PM systems have been already presented in Section 3.2.1.

thereby, fostering *improvements in decision-making processes* (Dumond, 1994; Mooraj *et al*., 1999; Kald & Nilsson, 2000). Being accountable for their actions and the way public money is spent, public decision-makers may be induced to pay more attention to the performance of PV systems throughout the entire life cycle. Indeed, spending public money just for financing the installation of PV systems – without taking care of the PV plant performance after the installation phase – would represent a wastage of resources due to the potential side effects in terms of lower clean energy production. In order to avoid such a situation, public decision-makers may foster the implementation of actions *e.g*. PV maintenance operations aimed at improving the performance of the installed PV systems during their whole life cycle.

PM systems can also facilitate *organizational changes*. For example, suppose that public organizations decide to change their culture by giving top priority to environmental protection and quality through the adoption of PV systems. To this end, PM systems can be used to align the organizational culture (Wellins & Schultz Murphy, 1995) with the goals and objectives (Aguinis, 2005). Thus, public servants may be trained with *ad hoc* programmes to improve their skills and knowledge (*e.g*., programmes on methods for environmental data analysis) in order to make change possible.

Moreover, PM system carries the promise of change to an achievement-driven performance culture through a *focus on results* rather than on the fulfillment of procedures (Dumond, 1994; Jorm *et al*., 1996; Lawrie *et al*., 2004; Neely *et al*., 2004). Therefore, a PM system allows measuring the outputs related to the PV investments, installation and usage of PV plants such as, for instance, the number of PV modules installed, the total capacity installed, and the number of defects/breakdowns of PV components.

According to Jorm, Hunt, & Manning (1996), a PM system may support a *better strategic planning* (Tapinos *et al*., 2005) through the processes of identifying and linking the objectives and strategies of the organization to the tasks of each public servant. It may also support public decision-makers in identifying areas of intervention and it may create a culture based on *continuous improvements* through the setting of more and more ambitious targets *e.g.* CO_2 emission reduction targets, or PV power to be installed.

Table 3.1 summarizes the main advantages of PM systems and lists the literature sources in which these have been found.

Advantages	**Literature source**
Higher innovativeness	Sim & Koh, 2001; De Waal, 2002; Brown, 2004; Self, 2004
More clarity for organizational members about their roles and goals to be achieved	Lawson *et al.*, 2004; Neely *et al.*, 2004; Papalexandris *et al.*, 2004
Higher commitment of organizational members to the organizations	Malina & Selto, 2001; Shulver & Antarkar, 2001; Robinson, 2004; Lawson *et al.*, 2005
Higher employee satisfaction	Sim & Koh, 2001; Papalexandris *et al.*, 2004
Improvements in decision-makers' accountability	Lovell *et al.*, 2002; Baraldi & Monolo, 2004; Heras, 2004; Lawson *et al.*, 2004
Improvements in the decision-making processes	Dumond, 1994; Mooraj *et al.*, 1999; Kald & Nilsson, 2000
Facilitation of organizational changes	Aguinis, 2005
More focus on the achievement of results	Dumond, 1994; Jorm *et al.*, 1996; Lawrie *et al.*, 2004; Neely *et al.*, 2004
Better strategic planning processes	Jorm, Hunt, & Manning, 1996; Tapinos *et al.*, 2005

Table 3.1. The contributions of Performance Management systems (Source: Adaptation from Kourtit & De Waal, 2008).

Beside the above advantages, the traditional PM systems also present some limitations.

Firstly, they are primarily based on financial models, measures, and information (Goold, 1991; Kald & Nilsson, 2000) with the risk to neglect other equally important non-financial ones (Cosenz & Bianchi, 2013).

Such a narrow focus can be due to two main factors: public sector financial constraints on the one hand and difficulties in designing and implementing non-financial measures within the conventional PM systems.

Accordingly, conventional financially-focused PM systems may generate a dysfunctional behavior known as "tunnel vision"[124], which can be defined as "an emphasis on phenomena that are quantified in the performance scheme at the expense of unquantified aspects of performance" (Smith, 1995: 284).

As a result, public decision-makers may tend to distort financial resource provision towards those programs where the link with the performance scheme is more direct and obvious (Smith, 1993).

Based on this, public decision-makers may allocate resources to those programs that promise financial benefits or cost minimizations to the detriment of other programs that mainly guarantee non-financial benefits.

This can be the case, for instance, of PV systems whose adoption and use may allow public organizations to achieve non-financial benefits (*e.g.*, environmental quality improvements) that are not easily quantifiable within the conventional PM systems. Therefore, given the high initial PV costs and the low (or lack of) focus on non-financial benefits, public decision-makers may discourage the adoption and use of PV systems.

Furthermore, traditional PM practices are mainly focused on an organizational (institutional) level of analysis although, in public organizations, a focus on an inter-institutional level is also needed in order to assess their policy outcomes[125].

Indeed, assessing performance primarily on an institutional level implies a lack of linkage between outputs and outcomes[126] that, in turn, may lead to a breakdown

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[124] Vakkuri & Meklin (2006) observe that the possible dysfunctions come from different theoretical and methodological underpinnings such as the theory of accounting as of the tunnel vision.

[125] At an institutional level, performance is primarily assessed in relation to the effects produced by decision-makers on their own institutions whereas at an inter-institutional level, performance is assessed in relation to the effects produced by decision-makers on the wider system (Bianchi, 2010). This is better explained in Section 3.4.

[126] Output measures are volume or workload indicators whereas outcome measures outline the aptitude of outputs in generating a change in the endowment of strategic resources related to the wider system. For such a reason, outcomes can be managed and measured only if a broad perspective – in both time and space – is adopted (Ammons, 2001; Bianchi, 2016). For instance, output measures can be the number of PV plants installed on public buildings, the amount of green energy produced by PV plants expressed as kWh/year or the quantity of CO_2 emissions avoided expressed as kg/year. As regards outcome measures, they can be identified in terms of change in environmental quality, or improvements in community's quality of life.

in the coordination between politicians and managers as well as to the adoption of a departmental view[127] of administration (Bianchi, 2016).

In addition, the lack of an outcome-oriented perspective by public decision-makers does not allow them to understand to what extent their policies contribute in creating value for the wider system/community (Moore, 1995), which, in turn, may feed back to the public organizations. Indeed, both the institutional and inter-institutional levels are interconnected each other.

For instance, the adoption and use of PV systems by local governments – as part of environmental policies addressed to limit CO_2 emissions – may contribute to create new value for the wider system in terms of environmental quality and local area's image, which together may affect the local area's attractiveness. An improvement in local area's attractiveness may generate further public value since it may foster economic activities (*e.g.*, tourism). Finally, part of this new value may feed back – sooner or later – to the local public organizations in terms, for instance, of tax contributions or consensus.

By focusing on an institutional perspective, traditional PM systems are not able to take into account the long-term effects *alias* outcomes produced by public policies on the wider system in which public organizations operate, as briefly presented above. Thus, public policy-makers may be inhibited to design, implement and encourage policies for PVs although these latter may foster the pursuit of a sustainable development.

Today, the shift towards an outcome-oriented and inter-institutional view of performance is still challenging due to the difficulties of traditional PM systems in framing the public sector's specific complexity (Rainey & Han Chun, 2005).

PM systems can be considered suitable tools when implemented for managing "static complexity" while they are lacking in relevance when applied to contexts characterized by high degrees of complexity, unpredictability, and environmental turbulence (Sterman, 2000).

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[127] Spitzer uses the term "suboptimization" to indicate "the practice of focusing on, or making changes to, one component of the total system, without considering the impact on the whole" (2007: 31).

As such, they often lack to capture the "dynamic complexity"[128] that typically characterizes the public sector in terms of delays between causes and effects of adopted policies, intangibles, multiple feedback loops and trade-offs in both time and space[129] (Bianchi, 2012a).

For instance, local governments may implement environmental policies for reducing pollution through the installation and use of PV systems on their public buildings.

A high percentage of clean energy, produced from PV plants, may allow limiting CO_2 emissions thus improving – *ceteris paribus* – environmental quality. This is likely to positively affect the local area's attractiveness that, in turn, may have an effect on the attractiveness of funds to be used for installing other PV plants.

However, in the long-term, a higher local area's attractiveness may lead to an increase of population and, then, to an increase of household electricity consumptions or an increase in urban mobility. If such needs are not fulfilled by means of clean energy, CO_2 emissions may increase thus adversely affecting environmental quality, which was the initial aim pursued by the local governments. In addition, the lower environmental quality may affect the local area's attractiveness and then the attractiveness of funds (or external contributions) to be allocated for financing new PV plants.

Such an example shows how unintended effects of public policies – generated *over a longer time horizon* – may not be promptly captured by the traditional PM systems.

Therefore, such systems may limit decision-makers' strategic learning processes (Kaplan & Johnson, 1987; Sloper *et al.*, 1999) and, then, the identification of alternative sustainable policies to counteract unintended effects in the long term.

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[128] Such a concept is widely discussed in Section 3.2.3.

[129] A policy may allow improving organizational performance in the short-term, but it may lead to unintended results in the long-term (trade-off in time). Also, it may improve performance in a given industry to the detriment of another (trade-off in space).

Ultimately, performance measurement/management schemes that tend to take heed of excessive short-term horizons may generate a dysfunctional behavior known as “myopia”[130], which may have some implications, *i.e.*:

- low priority to invest in long-term projects (*e.g.*, PVs);
- discouragement of projects promoting new ideas, “particularly when they present expenditures that promise long-term or less certain payoffs” (Merchant, 1990: 301)[131];
- potential improvements in the short-term organizational performance followed by lower (unintended) results in a longer time horizon, as in the previous example;
- poor and biased strategic decisions due to the difficulty to predict unintended results.

Suppose, for instance, that a municipality decides to install and use PV plants without carrying out PV maintenance at regular intervals.

In the short-term, it is likely that PV plants are still able to generate clean energy since the probability to record breakdowns may be very low.

However, in the medium/long-term horizon, such a myopic decision may imply a reduction of PV module efficiency thus leading to lower production of clean energy as well as lower CO_2 emissions avoided. That, in turn, may jeopardize the achievement of a sustainable development.

Finally, traditional PM systems may present other limitations, *i.e.*:

- poor selectivity of performance indicators[132] (Dumond, 1994; Kald & Nilsson, 2000; Self, 2004) with the risk to undermine the identification of the most suitable levers to be used in order to steer organizations towards the

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[130] Managerial myopia may tend to “arise whenever there is a lack of congruence between the time horizon of the managers and the time horizon of the projects for which they are responsible” (Smith, 1993: 143).

[131] This situation is nearly similar to another distorting effect known as “ossification” that occurs whenever “the system fails to react to new challenges or opportunities” and public managers do not have any incentive to look beyond the world encompassed in their performance indicators (Smith, 1993: 146).

[132] The design of an excessive number of performance indicators (PIs) may translate into an excessive information overload with the subsequent risk to paralyze the decision-making process (Mayne, 2007). Indeed, a high number of PIs may produce more noise than useful information; this is the so-called DRIP (Data Rich but Information Poor) syndrome (Poister & Streib, 1999).

achievement of strategic goals and objectives (Bianchi, 2004; Cosenz, 2011; Bianchi & Williams, 2015);

- unreliable or absence of *ad hoc* performance indicators for measuring outcomes with the risk to reinforce the mistaken conviction by decision-makers that "*what gets measured, gets done that what does not get measured, does not get done*" (Van Dooren, 2011: 423)[133].

Given the above limitations of traditional PM systems, Van Dooren (2011) has outlined two different strategies for dealing with them *i.e.* the single and double loop strategies (Argyris & Schön, 1996).

In particular, the first strategy aims at providing some recommendations for better implementing PM tools whereas the second one would suggest new alternative ways of doing PM, meaning that one does not need to try it again but to do it in a different manner.

As for the second strategy, here the combination of traditional PM systems with the SD methodology is suggested in order to overcome the limitations of the first ones.

Before discussing the main features of the methodological framework resulting from such a combination (*i.e.* DPM approach), the next subsection introduces the SD methodology.

3.2.3. *System Dynamics methodology for dealing with the complexity of public sector organizations and enhancing decision-makers' strategic learning processes.*

SD is a methodological approach[134] developed at MIT during the 1950s by Jay Wright Forrester, whom brought together ideas from three different fields *i.e.* control engineering, cybernetics, and organizational theory (Meadows, 1976).

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[133] Actually, performance measurement should primarily focus on outcomes since they are the most important key results for citizens and community in general (Hatry, 2002). For instance, it does not matter how many PV investments have been carried out (which is an output) but rather the community would be much more interested in higher environmental quality (which is an outcome). This means that there is a compelling need/challenge to "counting the uncountable".

[134] See Forrester, 1961; Sterman, 2000; Morecroft, 2007; Warren, 2008.

At the beginning, it was applied to manage typical problems of industrial firms and to date it applies to a wide range of fields such as for designing and evaluating public policies.

Most notably, SD methodology covers a wide range of public management issues (Ghaffarzadegan *et al.*, 2011) *e.g.* energy, environment (Fiddaman, 1997; Ford, 1997; Sterman, 2008), climate change and sustainable development (Honggang *et al.*, 1998).

SD may be defined as a "perspective and set of conceptual tools that enable us to understand the structure and the dynamics of complex systems" (Sterman, 2000: VII).

The basic principle is that if structure is responsible for determining the system behavior and if this latter is, in turn, responsible for determining performance, then one should understand the relationship between structure and behavior in order to steer organizations towards the achievement of sustainable development (Davidsen, 1991; Richardson & Pugh, 1981; Ghaffarzadegan *et al.*, 2011; Cosenz & Noto, 2016).

Unlike traditional PM systems, SD is able to deal with two main factors, which may be summarized as follows:

- a structural element (*i.e.* related to the reference social systems) that is the "dynamic complexity" (Bisbe & Malagueño, 2012);
- a subjective element (*i.e.* related to human cognitive abilities) that is represented by the limits of conventional "mental models" of decision-makers[135].

As far as the *dynamic complexity* is concerned, it arises because systems – in which public decision-makers operate – are (Sterman, 2000: 22)[136]:

- **dynamic**: which means that nothing is static but rather "all is change". Dynamics arises because of the existence or interaction between different feedback loops, whose neglect may lead to policy resistance;

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[135] According to Norman (1983), mental models are incomplete, stable and unscientific.

[136] See also Forrester, 1961; Richardson, 1996b.

- **governed by feedbacks**[137]: meaning that decisions change the state of the world and due to some effects produced by such decisions on the wider environment, a new situation will arise that, in turn, will affect further decisions;
- **nonlinear**: effects are not always proportional to their causes. Nonlinearity may often arise as multiple factors interacting in the decision-making processes;
- **counterintuitive**: in complex systems, causes and effects are often distant in both time (*i.e.* the so-called "delays") and space while decision-makers tend to observe phenomena by looking for causes near the events they seek to explain;
- **characterized by trade-offs**, which may be in both time and space. In particular, high leverage policies often cause "worse-before-better" interventions, while low leverage policies usually tend to generate temporary improvements. In this latter case, it is extremely likely that organizational performance may worsen in the long term *i.e.* "better-before-worse" thus overturning the logic behind high leverage policies.

As regards the *mental models*[138], they consist of implicit or explicit beliefs – held in decision-makers' heads – about a given phenomenon and they are the result of past experiences, previous knowledge, observation, and apparent actual perceptions.

Both time horizon and system's boundaries – chosen for investigating a phenomenon under observation – are those acknowledged as relevant according to the *viewpoint* of decision-makers.

Mental models present high degrees of subjectivity and become more and more deficient in presence of complex systems since two main factors may act as "noises"

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[137] The concept of "feedback" represents the core of system dynamics modeling. Indeed, most of the complex behaviours arise from the interactions (feedbacks) among the component of a system, not from the complexity of the components themselves (Sterman, 2000).

[138] See Senge, 1990; Forrester, 1992; Richardson *et al.*, 1994; Sterman, 2000.

in the decision-making processes *i.e.* the "bounded rationality principle"[139] and "limited (or imperfect) information" about the state of the real world[140].

Bounded rationality and limited information may not allow decision-makers to properly perceive the relevant boundaries of the system and the existence of feedback loops, whose neglect may limit their ability to learn (Figure 3.4).

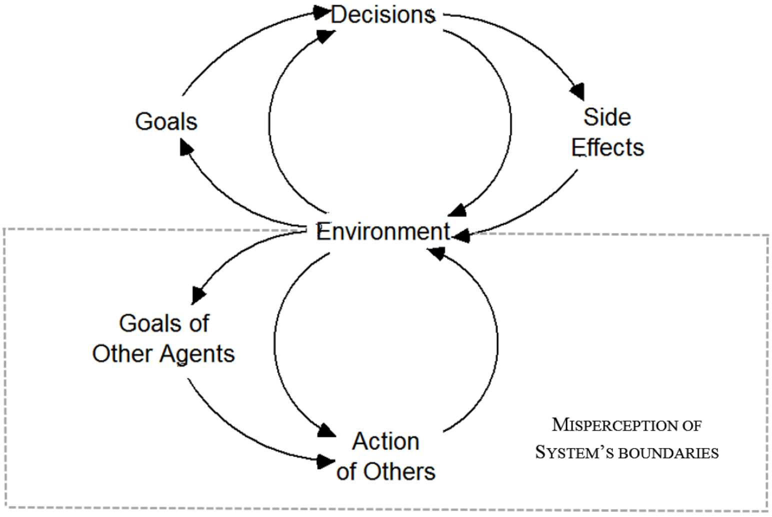

Figure 3.4. The perception of the system in presence of narrow system's boundaries (Source: Adaptation from Sterman, 2000, p. 11).

Thus, a misperception of system's boundaries may not allow public decision-makers to capture the side effects of their policies or strategic decisions.

Suppose that a local public organization decides to foster the adoption and use of electric cars in its local area in order to reduce CO_2 emissions.

At first sight, it could be considered a good effective decision for improving environmental quality since these cars do not emit carbon dioxide molecules when running.

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[139] Simon stated that "the capacity of the human mind for formulating and solving complex problems is very small compared to the size of the problem whose solution is required for objectively rational behavior in the real world or even for a reasonable approximation to such objective rationality" (Simon, 1957: 198).

[140] Indeed, bounded rationality is particularly acute in complex dynamic systems since public decision-makers tend to adopt a too static, linear, and bounded point of view in terms of both time horizon and systemic scope (Cosenz & Noto, 2016) as a result of the adoption of traditional PM systems. In this regard, Bianchi *et al.*, (2015) pointed out that framing organizational performance under a too static and narrow viewpoint means to misperceive the trade-offs existing both between short- and long-term effects (time) and between different organizational areas or departments (space).

However, what is not immediately intuitive is that such vehicles may contribute to increase rather than reduce CO_2 emissions since they are recharged by making use of electricity that, in most cases, is generated by fossil-fuelled power stations.

Such an example confirms how narrow boundaries may not allow decision-makers to understand and prevent unintended effects of their policies or strategic decisions.

In this context, a more sustainable policy may envisage the adoption of PV systems to produce clean energy in order to recharge the electric cars thus avoiding the above side effects.

Ultimately, public policies often fail to achieve their intended results because of the complexity of both the environment and the policy-making processes (Ghaffarzadegan *et al*., 2011), which are difficult to come up with the traditional PM systems.

A learning-oriented approach to planning and control[141] indeed implies the perception of the dynamic complexity, greater accuracy in setting system's boundaries and, thereby, improvements in coherence and complexity of mental models (Vennix, 1990) upon which lies the long-term sustainable development.

Figure 3.5 shows the modeling cycle as an iterative feedback process through which is made possible to go through continuous strategic learning.

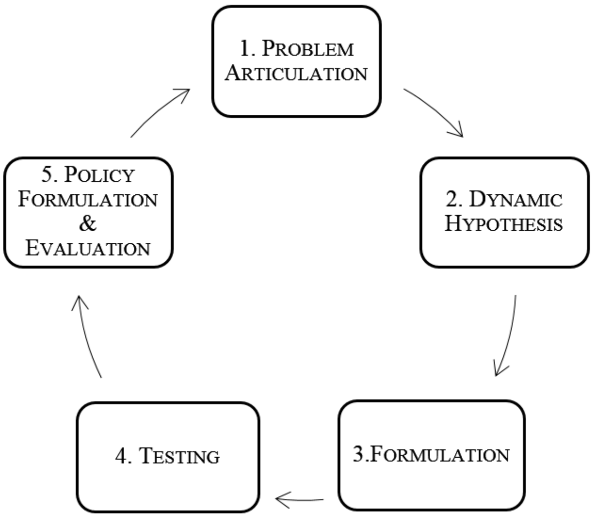

Figure 3.5. The modeling process as an iterative activity (Source: Sterman, 2000, p. 87).

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[141] For planning & control (P&C) systems, see Anthony, 1965 and Vergara, 2004.

Thanks to the building of SD models and the running of computer simulations, the resulting "virtual worlds" (Schön, 1983) aid to enhance the strategic learning processes of decision-makers and, thereby, the design and evaluation of public policies. That would limit the risk, in the real world, to discourage strategic decisions that – just for fear to worsen the PV sector performance or for the high underlying uncertainty – would not be adopted although they may yield to better results over a longer time horizon.

Indeed, one of the main advantages of such a "virtual world" is the possibility to test policies without any implication for the real world until they will be put into practice. Based on this, SD may support the formulation and evaluation of alternative public policies for PVs thus enabling decision-makers to understand to what extent their policies may contribute to improve the performance in terms of clean energy production.

In particular, SD may support traditional PM systems in two main ways *i.e.* by trying to explain the causes underlying a past situation and by simulating and testing the effects of alternative strategies under certain conditions (*e.g.*, "scenario analysis", or "what if analysis").

To conclude, public decision-makers' strategic learning processes would be fed by continuous comparisons between what actually happens in the real world on the one hand and what results from the simulation process in the virtual world on the other, with a view to fostering the achievement of sustainable development (Figure 3.6).

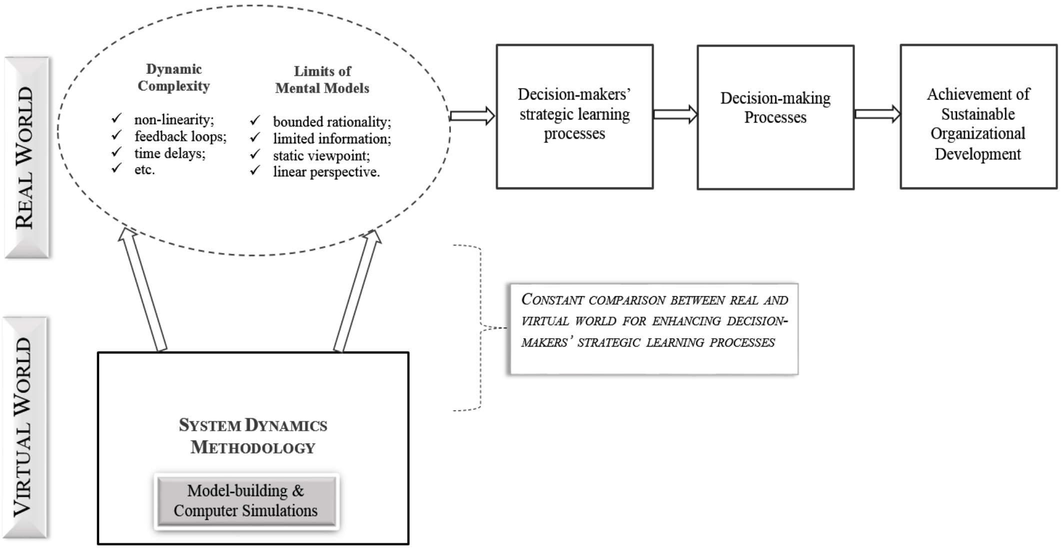

Figure 3.6. The contribution of SD methodology to deal with dynamic complexity and limits of mental models.

Based on the above introduction of SD methodology, the next subsection aims at presenting the framework resulting from the combination of SD with the traditional PM systems.

3.2.4. *Combining System Dynamics with Performance Management: the "Dynamic Performance Management" approach.*

In literature, major insights on the role that SD can play in enhancing the traditional PM systems are related to its support to decision-makers in managing organizational performance within a sustainability perspective[142] (Cosenz, 2011; Bianchi, 2012a; Bianchi *et al*., 2015).

By taking advantage from the main features and strengths of SD methodology, the combination of SD with the PM systems may allow public decision-makers to frame potential trade-offs in both time and space and to identify the causal mechanisms affecting results over time (Santos *et al*., 2002).

Therefore, such a combination may enhance public decision-makers' strategic learning processes by moving from single to double loop learning approaches[143] (Argyris, 1976).

Indeed, in double loop learning approaches, decision-makers may replace a narrow, short run, static view of the world with a holistic, broad, long-term dynamic view and, then, redesign their policies accordingly (Sterman, 2000).

As for the applications of SD to PM, one may discern two main streams of literature (Bianchi *et al*., 2015), *i.e.*:

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[142] Framing organizational performance according to a sustainability perspective implies the search for consistency between three perspectives *i.e.* the internal, external, and time ones (Bianchi, 2012a). As for the internal perspective, it relates to the search for consistency between different subsystems or departmental areas belonging to the same organization. As regards the external perspective, the search for consistency refers to the three most relevant "dimensions" for organizational success *i.e.* the financial, competitive, and social ones. Finally, time perspective outlines the aptitude of organizations to match short- with long-term horizons. See Greiner, 1972; Airoldi *et al*., 1989; Sorci, 2002; Catturi, 2007; Coda, 2010.

[143] Single loop learning is a process whereby people may learn to reach goals in the context of their existing mental models. Conversely, double loop learning approaches involves changes in mental models through information feedback from the real world (Argyris, 1985).

- the dynamic resource-based view of performance (Morecroft, 1984; Morecroft, 2007; Warren, 2008; Morecroft, 2013);
- the dynamic view of PM, known as "*Dynamic Performance Management*" (DPM) approach (Bianchi & Rivenbark, 2012).

Even though complementary, they present some differences in the way through which performance is framed.

As regards the "dynamic resource-based view of performance", the focus is primarily on "strategic resources", which represent tangible or intangible assets in a given time. They are acknowledged as "*critical success factors*" and the ability of decision-makers does lie in identifying and adequately managing them.

Therefore, under such a first perspective, the combination of SD with PM systems aims at developing models based on the building up and depletion of such core assets (*e.g.*, financial resources, environmental quality, and image).

As regards the "dynamic view of PM" *i.e*. DPM approach, organizational performance is primarily framed by focusing on those variables that – through the implementation of policies – change the endowment of strategic resources over a given time span. Such variables are the "end-results" and their related "performance drivers".

Particularly, ***end-results*** are usually represented as *in*- or *out*-flows depending on whether they accumulate or deplete the stocks of strategic resources, respectively[144]. For instance, change in environmental quality – that is an end-result – may affect the image of a local government, which is a strategic resource.

In order to steer public organizations towards the achievement of a sustainable development, end-results should embody both *output* and *outcome* measures.

For instance, as for the PV sector, output measures may be the kWh per year produced from solar PV panels installed on public buildings whereas outcome measures indicate to what extent the production of clean energy – by means of PVs – may contribute to the improvement of environmental quality.

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[144] Note that one may imagine different layers of end-results but only those ones positioned on the first layer are able to affect the endowment of strategic resources that cannot be purchased in the market, *i.e.*, liquidity and equity on the one hand and resources generated by management routines (that mainly refer to intangible resources) on the other (Bianchi, 2016).

Moreover, end-results can be affected through the ***performance drivers***, which are usually measured in relative terms *i.e.* as ratios between a current value and a target or benchmark one[145].

It is possible to identify three different types of performance drivers, *i.e.* the competitive, social, and financial ones (Bianchi *et al.*, 2015), which may allow public organizations to assess their performance under the external perspective of sustainable development.

Unlike end-results, performance drivers may be influenced in the short run thus enabling decision-makers to hopefully counteract future changes in the competitive, social, and financial end-results.

Finally, in order to affect performance drivers, each responsibility area must build up, preserve, and deploy a proper set of ***strategic resources***[146], which may also present interdependencies between them.

For instance, the strategic resource "PV capacity installed on public buildings" may affect the way through which the "local government's image" – that is another strategic resource – is perceived by citizens, or *lato sensu*, by community. This implies that the management of interdependent strategic resources should take place according to a systemic view.

The identification of end-results, performance drivers, and strategic resources outlines the "instrumental view of performance"[147], which is portrayed in Figure 3.7.

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[145] Particularly, the denominator of performance drivers may be defined in terms of perception of past performance, competitors' performance or a desired level that a given organization wishes to achieve (target or budget value).

[146] One may identify different kinds of strategic resources *i.e.* physical resources, information resources, capacity resources, and financial resources.

[147] Note that a DPM approach may be also applied by linking the instrumental view to two other views of performance management *i.e.* the *objective view* of performance and the *subjective view* of performance (Bianchi, 2010). Particularly, the "objective" view of performance implies the identification of products delivered to both external and internal users. The "subjective" view gives a synthesis of the two views of performance since it takes into consideration goals and objectives to be achieved, activities and processes to be carried out in order to achieve these goals as well as performance measures (*i.e.* performance drivers and end-results). For the purpose of this research study, the focus is only on the instrumental view of performance.

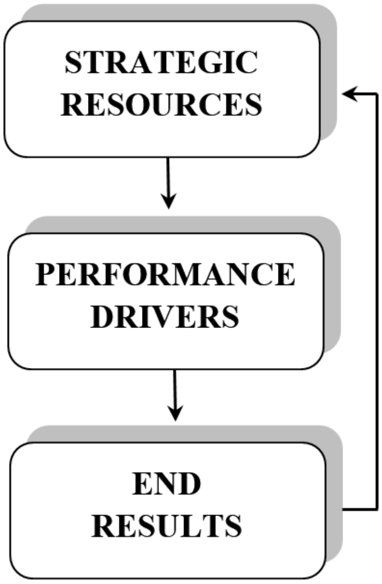

Figure 3.7. The "instrumental" view of performance (Source: Bianchi, 2012a, p.153).

In order to apply the instrumental view of performance, as a basis for designing and implementing a DPM approach, some tools are needed. To this end, the next section presents the qualitative mapping approach and the quantitative simulation modeling.

3.3. TOOLS FOR APPLYING A "DYNAMIC PERFORMANCE MANAGEMENT" APPROACH: "QUALITATIVE MAPPING" AND "QUANTITATIVE MODELING".

In order to apply a DPM approach, two tools – borrowed from the SD methodology – may be adopted, *i.e.*:

- ***qualitative mapping approaches***, which may take various labels *e.g*. causal loop diagrams, influence diagrams, and cognitive maps;
- ***quantitative simulation modeling***, which makes use of *ad hoc* software (*e.g.*, *Ithink*, *Powersim*[148], *Vensim*) for building a "Stock and Flow Model" (S&F)[149]. Unlike the first ones, the S&F models are expressed in quantitative terms.

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[148] See *http://www.powersim.com/*.

[149] A more detail of the S&F model is given in Section 3.3.2.

Although such tools may be jointly applied to address the same issue with the aim to yield additional insights into the dynamics, their relationship still seems to be fairly unclear and doubtful.

Some years ago, a research problem raised by Geoff Coyle (2000) indeed posed the following question: "*How much value does quantified modeling add to qualitative analysis?*".

Yet even before, Richardson (1996a) raised the following question: "*what are the wise uses of qualitative mapping approaches, and what are the conditions that require formal, quantitative modeling?*". In the same paper, he synthetized such a question as follows: "*when to map and when to model?*".

Actually, "the research issue is whether or not there are circumstances in which the uncertainties of simulation may be so large that the results are seriously misleading to the analyst and the client" (Homer & Oliva, 2001: 347).

Notably, uncertainties may concern the measurement of "soft variables" (*e.g.*, citizen satisfaction or image), the lack of numerical data to be used to formulate mathematical equations as well as the questionable value attributed to some parameters.

In SD practice, the above uncertainties are usually overcome by recalling the basic role of SD that is gaining general insights about the patterns of behavior rather than finding out the "precise" value of variables. Others argue the idea that SD is a well-suited methodology for addressing some challenges *e.g.* the measurement of soft variables or incomplete data (Homer & Oliva, 2001).

Stream of research has well documented that learning in and about complex systems without simulation does not allow one to deeply understand the dynamics of such systems (Richardson, 1991; Richardson, 1996a). In other words, the basic assumption is that it is very hard to grasp the dynamic implications without the aid of simulation modeling[150].

Despite such a line of reasoning, the early 1980s witnessed an increased development and use of purely qualitative modeling in which only cause and effect relationships were sketched without being followed by the building of simulation models (Coyle, 1999). Indeed, the spreading of qualitative tools was boosted by the

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[150] According to Coyle (1999), quantified simulation is the *sine qua non* of policy analysis.

basic idea that they could lead to reliable insights even without the use of formal and quantitative models (Richardson *et al.*, 1994; Richardson, 1996a).

It is not straightforward to say where the wise balance lies but here the adoption of both tools is suggested in order to successfully apply a DPM approach.

Indeed, although qualitative mapping approaches are useful tools for supporting public decision-makers in understanding the "*dynamic complexity*" (*i.e.* feedback loops), they are not able to capture the "*dynamics of the complexity*" (*i.e.* delays, nonlinearities, and accumulation processes). That is why qualitative mapping should be adopted alongside with the simulation models but, even then, one should keep an eye open.

It is important to remark that both the qualitative mapping approaches and the quantitative simulation modeling are *tools* that do not replace the reality but rather they seek to explain it and to provide additional insights in order to improve the thinking processes of decision-makers.

In the next two subsections, these two tools are better described by providing examples applied to the PV sector.

3.3.1. *Qualitative mapping approach: the "Causal Loop Diagram".*

Causal Loop Diagram (CLD) is a useful diagramming tool that allows capturing, eliciting and conceptually mapping one of the core concepts of SD methodology *i.e.* the feedback loop structure of the system under observation.

In particular, key variables are linked to each other by means of arrows according to the underlying causal relationships, which one believes be responsible for determining the dynamics of the system.

Causal relationships are made explicit through linkages between two (or more) variables *i.e.* the independent variable (cause) on the one hand and the dependent variable (effect or consequence) on the other; the first one is, therefore, what drives changes into the second variable.

Moreover, the dependent variable may, in turn, become an independent variable affecting another variable and so on until the loop is closed.

One may take over two ways through which the independent variable affects the dependent one, *i.e.*:

- direct (or positive) relationship;
- indirect (or negative) relationship.

In the first case, the causal link between the variables is marked with a positive sign ("+") meaning that if the cause *increases*, the effect – other conditions being equal – *increases* as well or, conversely, if the cause *decreases*, the effect – *ceteris paribus* – *decreases*, too[151].

Figure 3.8 portrays an example of direct relationship: the higher the installed PV capacity is, the higher the clean energy production will be and vice versa.

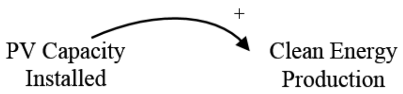

Figure 3.8. Direct or positive causal relationship: an example.

As for the indirect relationship, it is marked with a negative sign ("-"). Notably, a negative link polarity means that if the cause *increases*, the effect – other conditions being equal – moves towards the opposite direction namely it *decreases* and vice versa[152].

Figure 3.9 shows an example of indirect or negative relationship between two variables *i.e*. "CO_2 Emissions" – that represents the independent variable – and "Environmental Quality" representing the dependent variable.

An increase in CO_2 emissions released into the atmosphere will adversely affect the environmental quality whereas a reduction in CO_2 emissions – *ceteris paribus* – will improve the environmental quality. Since such a line of reasoning denotes an indirect relationship, the causal link is marked with a negative polarity (look at the sign close to the arrowhead).

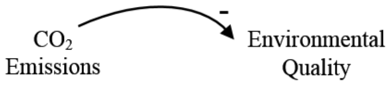

Figure 3.9. Indirect or negative causal relationship: an example.

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[151] Mathematically speaking, it means that $\Delta Y/\Delta X > 0$.
[152] It means that $\Delta Y/\Delta X < 0$.

Once the most important causal relationships between the variables have been identified, the next step is to check the polarity of the resulting feedback loops, which come into two distinct types:

- positive or reinforcing (R) feedback loops;
- and negative or balancing (B) feedback loops.

The first ones generate an exponential growth (or decline) behavior while the second ones involve the search for an equilibrium point over time (the so-called "*goal-seeking behavior*")[153].

Note that the combination of reinforcing and balancing feedback loops gives rise to different patterns of behavior (*e.g.*, S-shaped growth, overshoot and collapse)[154], which increase the complexity of the system.

Figure 3.10 shows an example of a qualitative CLD that consists of one reinforcing feedback loop and one balancing feedback loop.

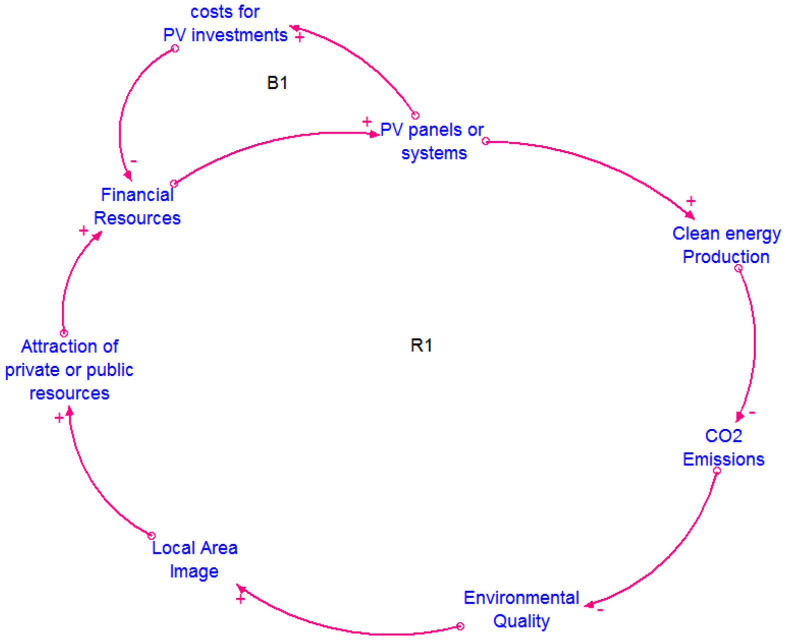

Figure 3.10. Qualitative mapping model composed by a reinforcing and balancing feedback loop: an example.

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[153] Note that there are two ways for determining the polarity of each feedback loop. The first simple way is just to multiply the signs (+/-) that label the causal relationships between the key variables. If the emerging result of such a multiplication is positive sign then the feedback loop is reinforcing otherwise it is balancing. The second right way for determining the loop polarity consists in tracing the effect of a small change in one of the variables and propagates it around the loop (Sterman, 2000: 144).

[154] Note that another mode of behavior is the so-called "oscillation" pattern that arises from negative feedback loop with time delays.

As Figure 3.10 shows, an increase in the number of PV panels purchased by public organizations – to be installed, for instance, on their own buildings – leads to an increase in clean energy production and, other conditions being equal, this will contribute to improve the environmental quality thanks to the reduction of CO_2 emissions released into the atmosphere[155].

One may expect that the implementation of sustainable energy policies and the direct investments on PVs by public organizations may translate – *ceteris paribus* – into improvements in their local area's image. Indeed, the implementation of such measures may contribute to improve the life quality of the citizens.

Finally, as a result of both their efforts and the better perceptions of their image by the overall community, public organizations may attract more (public or private) funds that can be used for financing further PV investments. What is described here represents the reinforcing feedback loop R1.

However, an increase in the number of PV systems purchased implies an increase in costs and, then, a reduction of financial resources (*i.e.* cash outflow for the purchase of PV systems). This describes the balancing feedback loop B1.

Although CLD allows one to better understand the causal relationships between the key variables, it suffers from a number of limitations.

Firstly, CLD does not distinguish between stocks and flows *i.e.* the accumulation processes of resources and the rates of change affecting resources, respectively. Indeed, in Figure 3.10, one cannot see what the stock or flow variables are, but just the way through which such variables are connected to each other.

Secondly, there is not any quantitative data and, therefore, it is not a straightforward task to infer the dynamics of the structure over time, due to the already discussed bounded rationality of humankind.

In order to overcome the above limitations, another tool can be used together with the CLD, *i.e.* the S&F model, which is presented in the next subsection.

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[155] The direct relationship between the variables may be considered in the opposite sense, as well. Thus, a decrease in the number of PV panels installed leads to a decrease in the generation of green energy.

3.3.2. *Quantitative modeling: the "Stock and Flow Model".*

From the previous discussion emerges the need to develop S&F models in order to improve the understanding of dynamic complex systems.

As Sterman emphasized, "without modeling, we might think we are learning to think holistically when we are actually learning to jump to conclusions" (1994).

S&F models underlie an unambiguous mathematical meaning, which is captured by the simulation software used for its building (*e.g.,* Powersim, Ithink).

Indeed, they are developed through the setting of mathematical formulas or equations that indicate the kind of relationship between the key variables of the system[156].

Once the equations have been set, the software allows simulating the patterns of behavior over time thus improving the understanding of the relationships between "structure" and "behavior".

Into a S&F model, the causal relationships between the key variables are displayed by making use of three distinct variables *i.e*. the stock, flow and auxiliary ones (Sterman, 2000).

Stock variables are usually represented by rectangles (Figure 3.11) and identify tangible and intangible resources in a given time. Stocks can change only through their flows. In accumulating their corresponding flows, stocks generate delays since the accumulation process is not instantaneous but it takes time[157]. In a DPM chart, strategic resources are represented as stock variables.

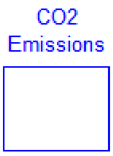

Figure 3.11. An example of "*stock*" variable.

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[156] Note that formulas correspond to a system of integral (in case of stock variables) or differential (in case of flow variables) equations.

[157] According to Mass (1980), stocks are critical in generating the dynamics of systems since 1) they characterize the state of the system and provide the basis for actions; 2) they provide systems with inertia and memory; 3) they are the source of delay; 4) they decouple rates of flow and create disequilibrium dynamics.

Flow variables can increase or deplete the stocks they affect; in the first case, they are called "inflows" while in the second case they are called "outflows". In a DPM chart, end-results are displayed as flow variables.

Graphically, inflows are represented by a pipe increasing a given stock while outflows are displayed by pipes that diminish the stock.

The difference between inflow and outflow gives the "net flow" that represents what changes the stock over a given time span. In particular, S&F models may show both inflows and outflows (Figure 3.12) or, alternatively, just one single variable (*i.e.* biflow) representing the net rate of change (Figure 3.13).

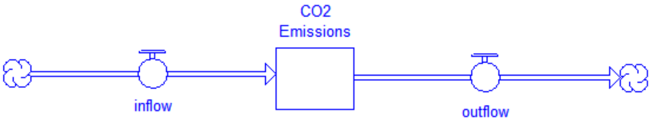

Figure 3.12. An example of "*inflow*" and "*outflow*" variables.

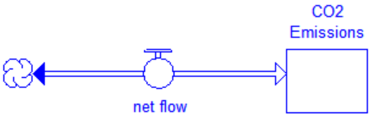

Figure 3.13. An example of "*net flow*" variable.

In order to distinguish between stocks and flows, one may use the so-called "snapshot test" according to which what is observable and, then, measurable *in a given moment of time* falls into the category of "stock variable" whereas what can be observable *over a given time span* constitutes a "flow variable".

Beside stock and flow variables, there may be *input parameters* that keep constant value throughout all computer simulations. They represent exogenous variables in relation to the investigated system or policy levers upon which policy-makers may act in order to affect the system.

The graphical representation of an input parameter is given in Figure 3.14[158].

Figure 3.14. An example of "*input*" parameter.

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[158] This graphical representation has been developed with Powersim software. Indeed, Ithink does not distinguish between input parameters and auxiliary variables: both of them are displayed as circles.

Finally, S&F models may include *intermediate or auxiliary variables* (Figure 3.15) that usually serve to make intermediate calculations.

Into a quantitative model, performance drivers are displayed as auxiliary variables.

Figure 3.15. An example of "*auxiliary*" variable.

Based on the example of CLD previously shown in Figure 3.10, a quantitative model has been built with Ithink software.

Such S&F model – composed of one reinforcing and one balancing feedback loop – embodies the stock, flow and auxiliary variables (Figure 3.16).

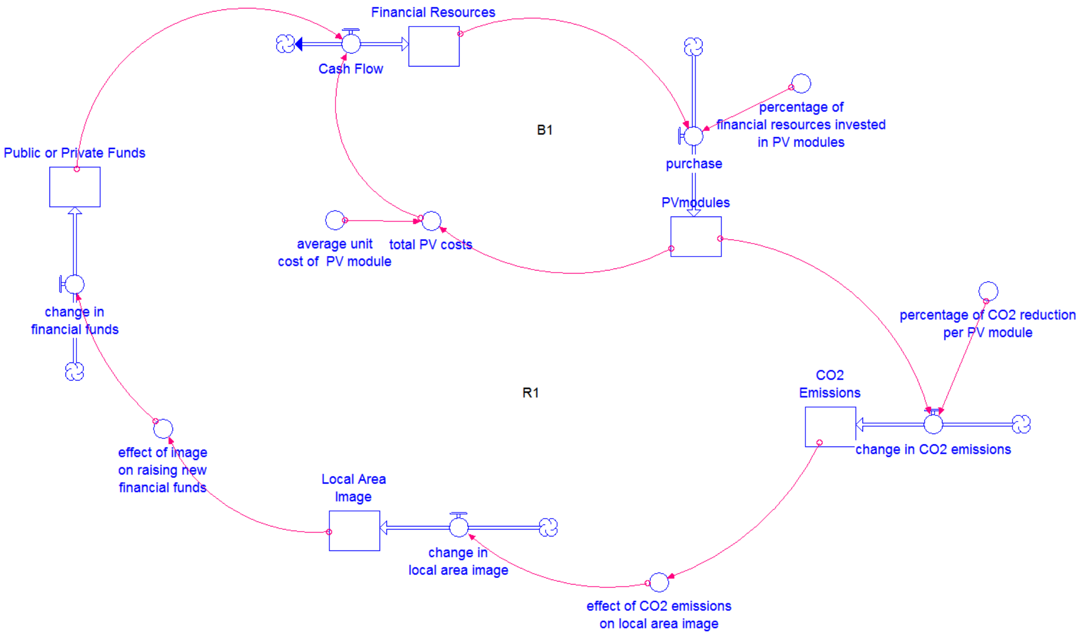

Figure 3.16. An example of quantitative model realized with Ithink software.

3.4. THE CONTRIBUTION OF A "DYNAMIC PERFORMANCE MANAGEMENT" APPROACH TO THE PV SECTOR IN PUBLIC ORGANIZATIONS.

As already discussed, a DPM approach is a methodological framework able to support public decision-makers in dealing with the dynamic complexity of the systems in which they operate.

One of the main advantages of such an approach lies in its aptitude to frame organizational development sustainability at two complementary levels of analysis *i.e.* the *institutional* and the *inter-institutional* ones.

Under the institutional perspective, performance is mainly assessed in relation to the results achieved by an organization that, in turn, arise from the implementation of policies and actions undertaken by the decision-makers.

Although it is important to know the effects produced by decision-makers' policies on the institutions, managing performance only under an institutional level cannot be considered enough for assessing the outcomes of public policies.

The achievement of sustainable development depends on the aptitude of public organizations to generate value *not only* at an institutional level *but also* at an inter-institutional one *i.e.* for the wider system to which they belong, which is characterized by the presence of multiple (public and private) "actors" (Bianchi, 2010; Bianchi, 2012a; Bianchi & Tomaselli, 2013).

Indeed, it is extremely likely that the effects *alias* outcomes that public policies may generate on the performance of the wider system – sooner or later – will feed back on the organizational performance.

Suppose, for instance, that some local governments – due to financial constraints or the need to achieve financial equilibria – decide to implement discretionary cost reduction policies. To this end, they may decide to not invest in PV systems thus reducing the production and use of clean energy for meeting their electricity demand.

In the short term, such a policy may allow public organizations to improve their financial performance. However, in the long term, some unintended effects – associated with the implementation of such a policy – may take place with the risk to generate even lower financial results.

Indeed, over a longer time horizon, the lack of PV investments would worsen – other conditions being equal – the environmental quality due to the higher CO_2 emissions released into the atmosphere since the electricity demand would not be met by means of RES_s. After a certain delay, that would negatively affect the community's life quality in terms, for instance, of health risks or even diseases triggered by environmental pollution. Such a situation may adversely affect public organizations' performance due to, for instance, the growing level of expenditure on healthcare for citizens that, in turn, may exacerbate financial difficulties.

In addition, lower environmental quality may translate into lower local area's attractiveness and, then, a reduction of population (*e.g.*, citizens may prefer living in less polluted environments). Finally, this will feed back to municipalities' performance in terms, for instance, of lower tax revenues.

Therefore, public policies – based on the reduction or lack of PV investments due to a narrow focus on the financial performance, on the short-term horizon, and on an institutional level – may lead public organizations towards even more financial problems in the long term.

The main feedback loops – associated with the implementation of the already described public policy – are portrayed in Figure 3.17.

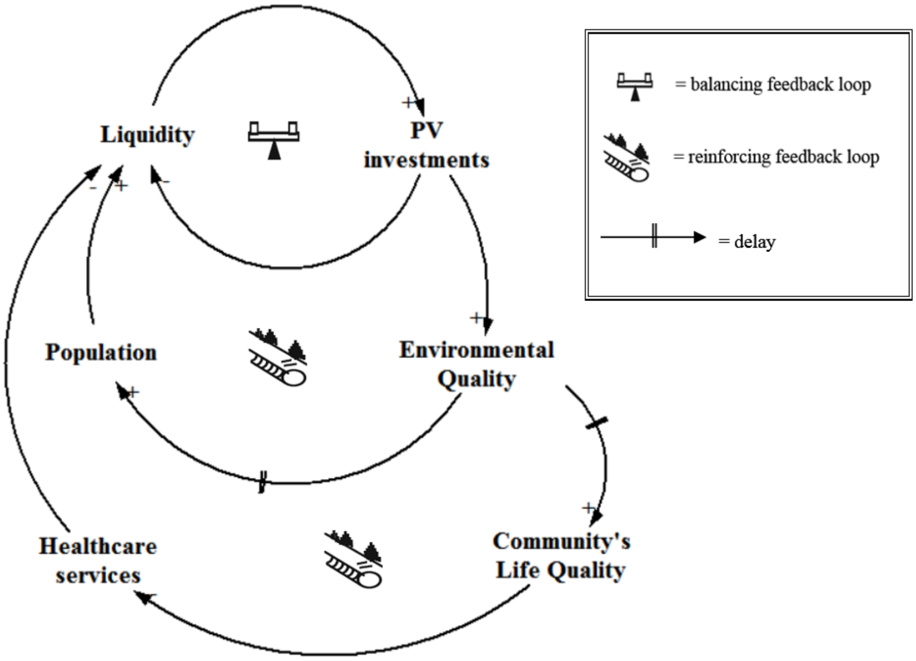

Figure 3.17. Unintended effects from indiscriminate reduction in PV investments (Adapted from Bianchi, 2016, p. 5).

Based on the above CLD, a DPM approach has been designed by adopting the instrumental view of performance. Thus, the main end-results, performance drivers, and strategic resources have been identified and portrayed in Figure 3.18.

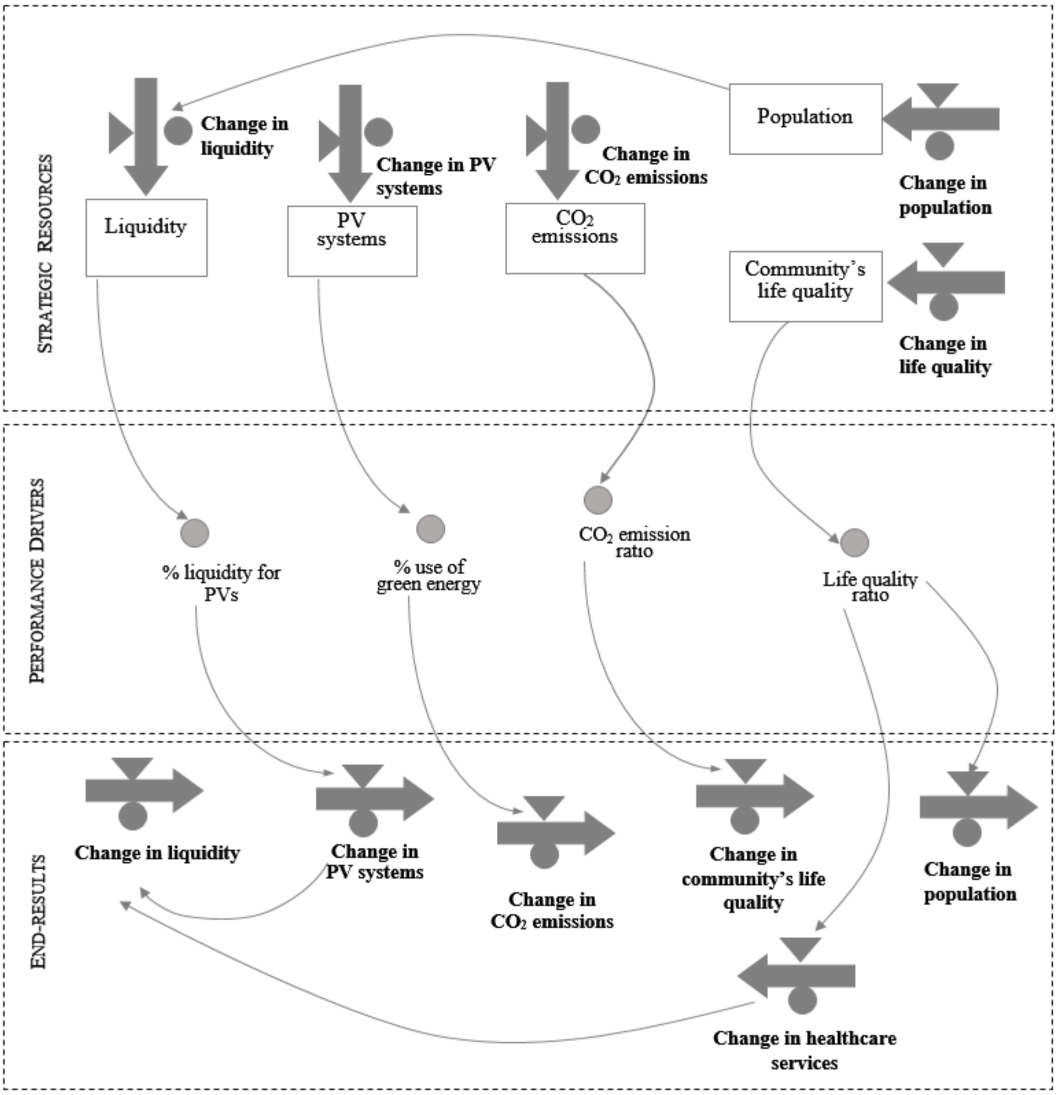

Figure 3.18. DPM chart portraying the effects from indiscriminate discretionary cost cutting.

Unlike the traditional PM systems, a DPM approach may enhance public decision-makers' strategic learning processes thanks to the framing of potential trade-offs in both short- and long-term horizons as well as the detection of delays between causes and effects of the adopted public policies. As a result, such an approach may support decision-makers in setting sustainable policies based on the adoption of PV systems with a view to achieving sustainable development in the long run.

Now, suppose that some public organizations decide to invest, install, and use a large number of PV systems in order to contribute to the generation of value for the wider socio-economic system to which they belong. It is likely that such a massive deployment of solar PV systems in the public sector will boost the PV industry *e.g.* in terms of employment opportunities (the so-called “green jobs”) or cost reductions of PV technology thanks, for instance, to the development of more efficient solutions (*i.e.* higher R&D intensiveness) or economies of scale.

One may expect that the positive effects – produced at an inter-institutional level – will feed back on public organizations’ performance thus generating new growth measured in terms, for instance, of tax contributions, improvements in municipalities’ image, and higher financial resources (*e.g.*, external contributions) to be allocated for financing further investments in PV systems.

Based on the above example, Figure 3.19 shows the two-way relationship between the institutional (A) and inter-institutional (B) levels. Notably, the institutional level is articulated into other sub-levels (a1, a2, …, aN) to indicate the presence of other public organizations whose actions may contribute to generate effects, either positive or negative, on the wider inter-institutional level.

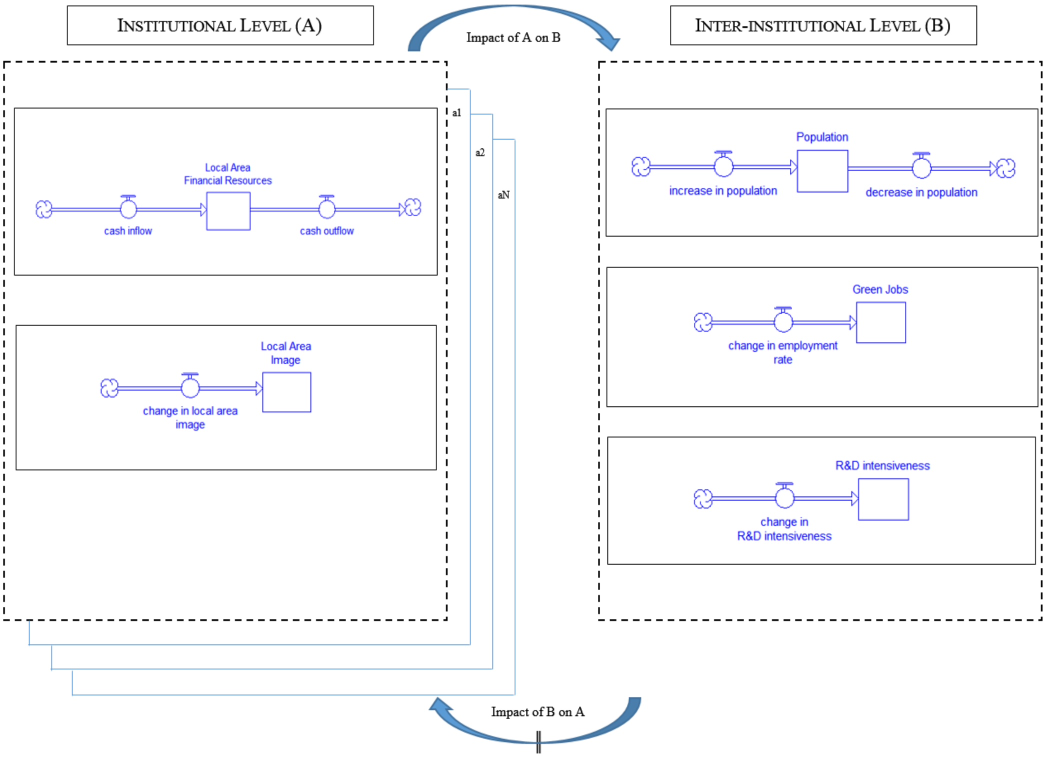

Figure 3.19. Two-way relationship between the institutional and inter-institutional level of performance.

Ultimately, the examples shown before suggest how the combination of SD with the traditional PM systems *i.e*. DPM approach can contribute to improve the design of public policies concerning PV investments, installation and usage since it can support decision-makers in:

- better framing trade-offs over time *i.e*. between short- and long-term horizon thus avoiding the adoption of a myopic view;
- identifying the potential side effects associated with a narrow focus on the financial performance (*i.e*. tunnel vision) and, thereby, fostering a broader view to frame performance within the sustainability perspective through the definition of financial, competitive, and social performance drivers (Figure 3.18);
- better understanding the linkages between the institutional and inter-institutional levels;
- managing performance at both an institutional and inter-institutional level of analysis in order to assess the outcomes associated with the implementation of public policies (Bianchi & Tomaselli, 2013);
- detecting delays between causes and effects of their adopted policies as well as the existence of balancing and reinforcing feedback loops.

In the next Chapter, the theoretical framework here outlined is supported by empirical evidences through the application of a DPM approach to the PV sector of Palermo Municipality.

CHAPTER 4

A DYNAMIC PERFORMANCE MANAGEMENT APPROACH TO THE MUNICIPALITY OF PALERMO: A CASE STUDY BASED ON THE PHOTOVOLTAIC SECTOR

This chapter presents major insights of a case study based on the PV sector in an Italian local government i.e. *Palermo Municipality, one of the first municipalities that undertook initiatives to promote energy efficiency and RES*$_S$. *After a short introduction of the "Sustainable Energy Action Plan" of Palermo Municipality, the focus is on the PV projects, the benefits associated with the adoption of PV systems (at both an institutional and inter-institutional level of analysis), and the stakeholders who are likely to affect or be affected by the outcomes of the PV projects. Subsequently, starting from the decreasing PV investment trend recorded over the last few years, an analysis of the main critical issues follows. Such an analysis reveals the presence of some barriers and the need for designing a DPM approach tailored to Palermo Municipality. To this end, the "DPM framework" and the "Causal Loop Diagram" are developed for the PV sector; both of them, in turn, represent the basis for the "Stock and Flow Model". Lastly, the chapter concludes with a discussion of possible policy options and related simulation results.*

4.1. INTRODUCTION.

The Municipality of Palermo – the capital of the autonomous region of Sicily (South of Italy) located in the Northwest Coast – is a public body at local level with a population of almost 680,000 inhabitants (Istat, 2016)[159].

Its organizational structure consists of different levels, which can be briefly listed as follows (Figure 4.1)[160]:

- the ***mayor*** representing the highest-ranking official, elected by the public;
- the ***legislative body*** (*i.e.* the "municipality council" or "consiglio comunale") and the ***executive body*** (*i.e.* the "municipal board" or "giunta comunale"), which represent – together with the mayor – the political level;

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[159] See: *http://demo.istat.it/bilmens2016gen/query.php?lingua=ita&Rip=S5&Reg=R19&Pro=P082&Com=053&submit=Tavola*.

[160] For a more detailed description, see the official website: *https://www.comune.palermo.it/organigramma.php*.

- the ***general manager*** (*alias* "direttore generale") representing the managerial level. Here, one may identify a number of offices (*e.g.*, security office, strategic plan office, and organizational development office) that collaborate with the general manager;
- ***specific areas*** related to the activities of the macro-areas of the municipality (*e.g.*, human resources area, budget/financial area, and environmental area). Each area, in turn, may be composed of several ***offices***, ***sectors***, and ***services***;
- finally, ***project units*** may be temporarily established with the aim to pursue specific objectives not directly related to the regular tasks assigned to each sector/office.

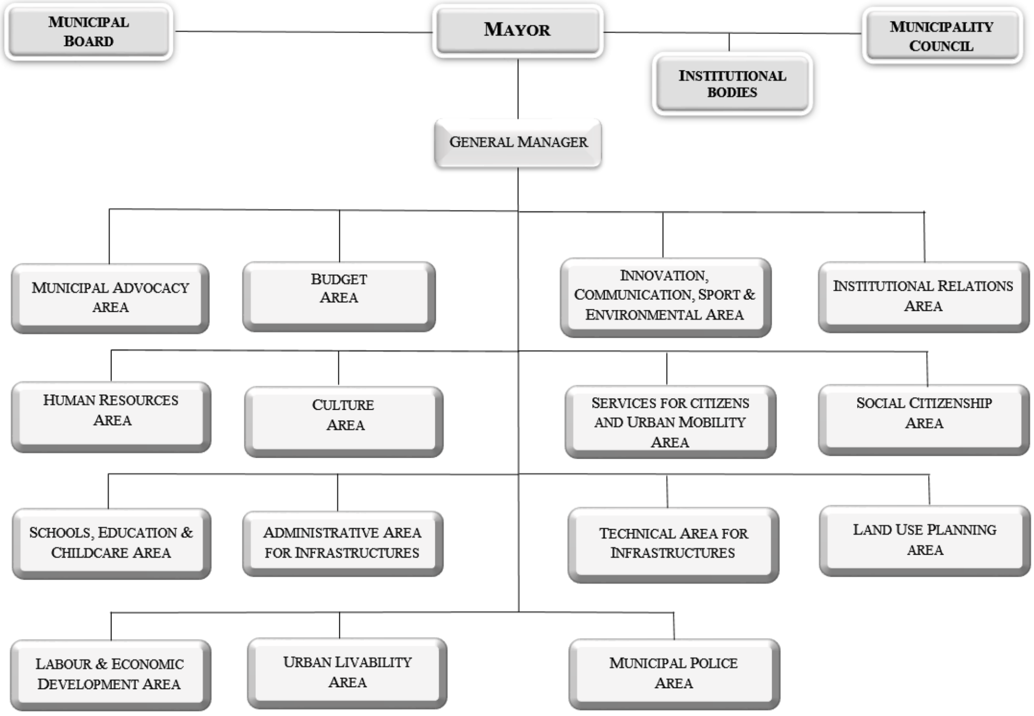

Figure 4.1. Organizational chart of Palermo Municipality.

In 2012, the Municipality of Palermo set up an *ad hoc* intersectoral structure *i.e.* the "*Covenant of Mayors-Project Unit*" – under the coordination of the Environmental Area – with the aim to support and coordinate its activities aimed at reducing by 2020 more than 20% of CO_2 emissions.

Since local governments are expected to play a leading role in pursuit of the sustainable development goals[161], the Municipality of Palermo pledged to contribute in mitigating the effects of climate changes through the implementation of a wide range of initiatives described in its "*Sustainable Energy Action Plan*" (SEAP)[162].

Particularly, among the wide set of actions, such a plan encourages the adoption of RES$_s$ in order to reduce CO_2 emissions released into the atmosphere.

Thus, starting from an analysis of data on its final energy consumption, the Municipality of Palermo has identified the priority areas that must be addressed by policies in order to achieve its emissions reduction targets for 2020.

In particular, most of energy is consumed for serving public buildings (*e.g.*, schools, offices, and sport facilities) and public lighting requirements, which together account for almost 80% of total energy consumption (Figure 4.2).

As such, these two energy-intensive areas are responsible for high CO_2 emissions, which account for almost 90% (corresponding to around 39,000 tCO_2) of total emissions.

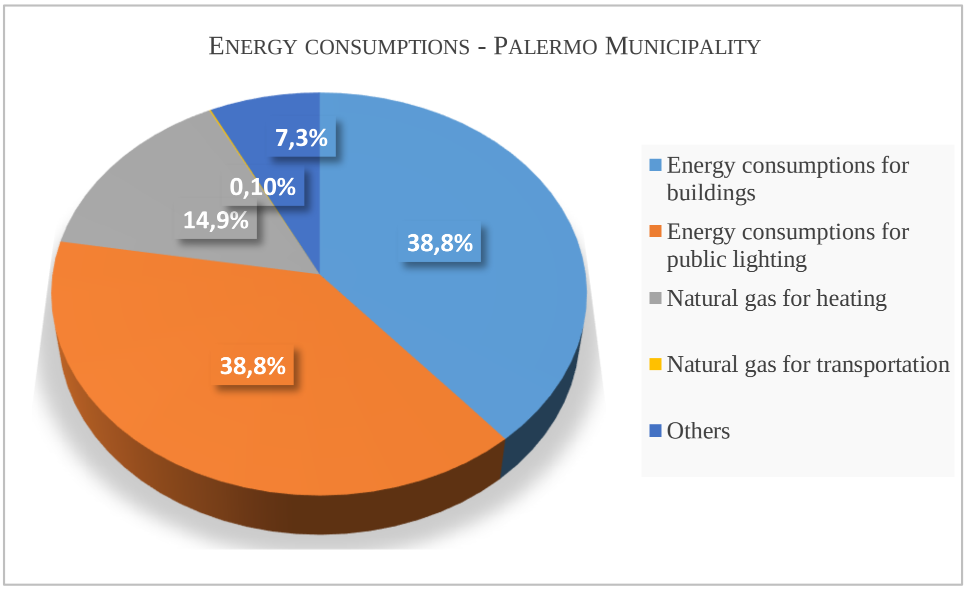

Figure 4.2. Final energy consumption of Palermo Municipality in 2009 (Source: SEAP of Palermo Municipality).

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[161] Note that this represents a core principle underlying the "Covenant of Mayors" initiative.

[162] The "*Sustainable Energy Action Plan*" – that represents a mandatory step for Covenant of Mayors' signatories – translates the political commitment into practical measures and projects. It is widely described in the next sections of this Chapter.

In such a context, the adoption of PV systems is posed as a promising technology given its high potential for energy efficiency improvements in public buildings and environmental impacts reduction.

Furthermore, the good level of solar radiation along with favorable weather conditions recorded in Sicily (GSE, 2014) would allow – *ceteris paribus* – high electricity production from PV panels thus making convenient the use of solar energy for meeting electricity needs of Palermo Municipality.

Notwithstanding, over the last years, the Municipality of Palermo has recorded a decreasing trend in the adoption of PV systems – even when the FIT scheme was still operative – mainly due to some barriers that represented a brake for their wide adoption.

Today, it seems that some critical issues – such as, for instance, bureaucratic and financial barriers as to the adoption of a tunnel and myopic view by decision-makers – still persist, with the risk to jeopardize the successful implementation of PV projects and, then, a wide adoption of PV systems in upcoming years.

Therefore, after an analysis of the main critical issues related to the adoption of PV systems, the design of a DPM approach – tailored to Palermo Municipality specifically for the PV sector – is provided.

The emerging DPM framework may support public decision-makers in improving their strategic learning processes and better understanding the dynamic complexity of the systems in which they operate.

Indeed, the implementation of such an approach may support decision-makers in understanding how performance drivers affect end-results and how these latter may affect, in turn, the accumulation and depletion processes of strategic resources (*i.e.* "instrumental view of performance").

Furthermore, the DPM approach may allow decision-makers to understand the interconnections between different organizational units (areas), namely how end-results of a given area affect strategic-asset accumulation and depletion processes of another area belonging to the same organization (in this case, Palermo Municipality).

Finally, as already anticipated in the first Chapter, the DPM approach is applied for developing a learning environment foresight model *i.e*. scenario analysis in order to test alternative policies.

4.2. RENEWABLE ENERGY ROADMAP FOR PALERMO MUNICIPALITY: THE "SUSTAINABLE ENERGY ACTION PLAN".

Local governments play a crucial role in formulating policies and implementing countermeasures – tailored to the characteristics of their territories – in order to reduce anthropogenic GHG emissions.

Palermo was one of the first Italian municipalities to undertake projects and initiatives addressed to promote energy efficiency and RES$_s$ through, for instance, the approval of the "Municipal Energy Plan" (MEP)[163], the "Climate Alliance for Mediterranean Cities" (MedClima)[164], and the "Zero Emission Neighbourhoods" (ZEN)[165].

Notably, the last two projects might be considered forerunners of the "Covenant of Mayors", a European movement involving a considerable number of local and regional authorities to fight climate changes.

In 2011, under the EU Covenant of Mayors initiative, the Municipality of Palermo pledged to reduce CO_2 emissions by more than 20% of EU objectives by 2020[166].

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[163] The MEP was approved by the City Council (*alias* "Giunta Comunale") with deliberation of 09/08/2000.

[164] Palermo Municipality joined such a European project in 2002 with the aim to formulate a guideline for local climate protection and easy steps for reducing CO_2 emissions. For more details, see *http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=2155&docType=pdf*.

[165] Palermo Municipality joined the project during the years 2004-2005, which the aim to foster the adoption of RES at a local level. As part of this project, in 2009 Palermo Municipality undertook an initiative to energy requalification of "Paolo Borsellino kindergarten" that won the "Environmental and Social Sustainability Prize" promoted by "Ancitel Energia e Ambiente" and "Saint-Gobain Sistema Habitat".

[166] In particular, Palermo Municipality adhered to the Covenant of Mayors initiative with the deliberation 29/12/2011 of City Council, which was ratified by the Town Council (*alias* "Consiglio Comunale") with the deliberation 06/05/2013.

Such a strategic goal – based on more secure, sustainable energy – had to be translated into a series of steps thanks to the support of an *ad hoc* intersectoral structure under the coordination of the Environmental Area *i.e.* the "Covenant of Mayors-Unit of Project".

Specifically, these steps may be summarized as follows:

- the drafting of the "Sustainable Energy Action Plan" (SEAP)[167] outlining the key actions ranked by priority[168];
- the preparation of a baseline review *i.e.* the "Baseline Emission Inventory" (BEI)[169] to track mitigation actions;
- the writing of the "Progress Report" every two years following the submission of the plan to monitor to what extent objectives are achieved.

Starting from the basic idea that climate change is a complex cross-cutting issue, the SEAP of Palermo Municipality is based on a paradigm promoting better collaboration and greater integration between the different structures and key-actors involved, in line with a joined-up government (JUG) approach[170] (Christensen & Laegreid, 2007).

Based on this, the SEAP aims at:

- strengthening the collaboration between the Municipality of Palermo and the primary stakeholders with reference to the SEAP actions to be implemented[171];

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[167] The Town Council approved the SEAP with the deliberation no. 82 of 31/07/2015. The SEAP text can be found on the following webpage: *https://www.comune.palermo.it/js/server/uploads/_10072013112515.pdf*.

[168] The SEAP has identified three distinct types of actions according to their priority: actions with high priority (A) having a high potential to reduce emissions; actions with low priority (B) having a low contribution to reduce emissions and finally not quantifiable actions (NQ) that are strictly related to other actions.

[169] A Baseline Emission Inventory is a quantification of the amount of CO_2 emitted due to energy consumption in the territory of a Covenant signatory within a given period of time. It allows identifying the principal sources of CO_2 emissions and their respective reduction potentials (Source: *http://www.covenantofmayors.eu/+-Baseline-Emission-Inventory-+.html*). Palermo Municipality has considered the 1990 recommended base year.

[170] Indeed, such an approach – also known as "whole of government" approach – aims at enhancing coordination between different levels of government, agencies, ministries and other administrative units to achieve successful design, implementation, and evaluation of public policy design (Bianchi & Williams, 2015).

[171] To this end, in April 2013 the Municipality of Palermo has published a notice on its web site for the setting up of a "Register of Stakeholders" and interest groups in order to further a fruitful dialogue to successfully implement SEAP actions.

- involving public and private organizations (*e.g.*, Universities, and Energy Agencies) to carry out training programs on environmental sustainability issues addressed to Palermo Municipality's employees;
- furthering collaboration between different offices inside Palermo Municipality's organizational structure in order to support employee training programs (*e.g.*, learning about new data collection techniques);
- sharing results with other fellow (local) public authorities as well as taking advantage of other European pilot projects;
- promoting collaboration with local schools in order to raise students' awareness on RES_s and on current environmental issues through *ad hoc* education projects.

Furthermore, the SEAP might represent a "strategic tool" for achieving a wider goal for Palermo Municipality, which is to become the 2019 European Capital of Culture (ECoC)[172] through the implementation of a project aimed at improving its local image and, thereby, gaining social, cultural, and financial benefits.

The successful implementation of SEAP actions may allow Palermo Municipality the building up (or improvement) of a given endowment of strategic resources such as environmental quality, local area image, knowledge, infrastructures, and local attractiveness, which may yield benefits to the performance of the whole territory thus contributing to the achievement of the broad goal for 2019.

The SEAP of Palermo Municipality sets up three main areas of intervention, *i.e.*:

- energy efficiency improvements and use of RES_s (area of intervention 1);
- sustainable transport (area of intervention 2);
- and finally information, training/education programs and communication (area of intervention 3).

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[172] The European Capital of Culture is a city designated by the EU for a period of one calendar year during which it organizes a series of cultural events with a strong European dimension. Preparing a European Capital of Culture can be an opportunity for the city to generate considerable cultural, social and economic benefits and it can help foster urban regeneration, change the city's image and raise its visibility and profile on an international scale (Source: *https://en.wikipedia.org/wiki/European_Capital_of_Culture*). For more details, see *https://ec.europa.eu/programmes/creative-europe/actions/capitals-culture_en.*

Each area of intervention, in turn, embodies a set of actions and measures. Finally, performance indicators, estimated costs, expected CO_2 emission reductions and funding sources are made explicit for each action[173].

By 2020, it is expected that the implementation of SEAP actions will lead to a reduction of CO_2 emissions equals to 400,000 tons, a decrease – compared to 1990 levels – of almost 22%.

A general framework of SEAP is given in Figure 4.3.

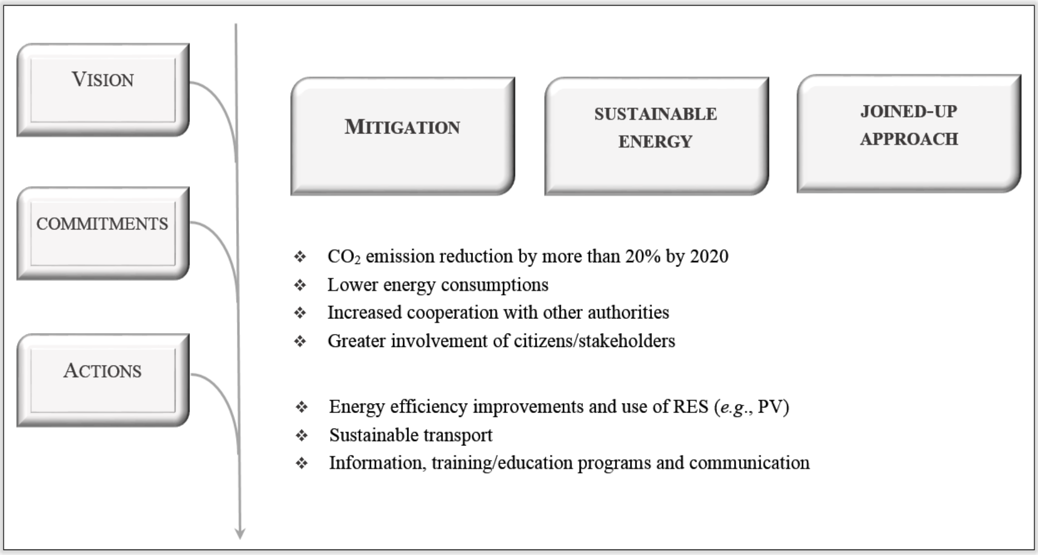

Figure 4.3. Synthetic representation (framework) of SEAP.

4.3. PV PROJECTS: FOCUS ON ACTION 1.17 OF SEAP.

Among the wide range of strategic actions, the SEAP envisages the installation of PV plants on public buildings owned by the Municipality of Palermo[174].

In particular, such an action[175] – identified as "Action 1.17" – presents the following key points:

- high priority (symbol A);

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[173] Notably, the total cost of the actions included in the SEAP has been estimated to € 1.182.957.363,07 to be covered by using different funding sources (*e.g.*, EU funds, national and regional funds, Palermo Municipality's financial resources, bank loans, or third-party financing).

[174] In particular, the total assets owned by Palermo Municipality amount at almost 1,780.

[175] Note that such action envisages the installation of solar thermal systems, as well.

- high contribution to CO_2 emission reduction (almost 690 tCO_2/year avoided);
- involvement of a wide array of stakeholders (*e.g.*, departments of Palermo Municipality, banks, PV manufactures, and Energy Service Companies);
- total PV capacity to be installed equals to 1 MWp;
- total estimated cost of the action equals to 2,5 million euro[176].

The successful implementation of Action 1.17 requires the fulfillment of a set of activities that Palermo Municipality has to carry out, *i.e.*:

- identification of public buildings considered eligible for the installation of PV plants;
- employee training programs on the role/advantages of RES_s and the design of PV systems;
- monitoring of PV project implementation;
- communication of PV project results.

As regards the last point, the installation of PV plants may allow Palermo Municipality to attain significant benefits (results) at both an institutional and inter-institutional level.

At an institutional level of analysis, the SEAP would take into account the non-financial and financial advantages, for Palermo Municipality, arising from energy diversification, upskilled employees, energy cost savings and reduction of PV installation costs thanks to the (potential) development of the PV industry.

Indeed, at an inter-institutional level, it is extremely likely that PV projects – promoted by Palermo Municipality – may represent an “input” for furthering technological progress in PV manufacturing processes. If so, PV manufacturers may gain economies of scale in production and, as a result, they may set lower PV prices.

Yet, at an inter-institutional level, the increase in electricity production from PV systems may lead to environmental quality improvements thanks to the expected CO_2 emission reductions thus transferring public value to the whole community in terms, for instance, of better life quality.

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[176] Actually, such an amount includes also costs related to investments in solar thermal systems.

Finally, PV systems installed in school buildings (or sport facilities) are supposed to play an education role for students (or, more generally, citizens) by raising their awareness of the advantages associated with the adoption and use of sustainable energy.

Figure 4.4 illustrates the major benefits that Palermo Municipality is expected to get through the implementation of PV projects.

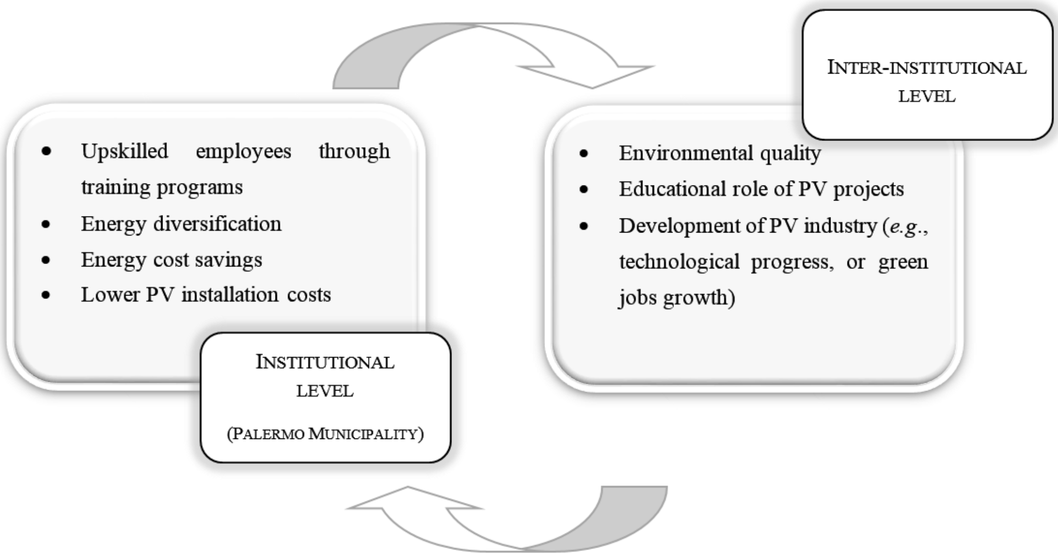

Figure 4.4. Palermo Municipality's PV projects: relationship between the institutional and inter-institutional level.

4.4. LISTING POTENTIAL STAKEHOLDERS FOR PV PROJECTS.

The successful development and implementation of PV projects in the Municipality of Palermo (Action 1.17 of SEAP) implies a close look at all those primary stakeholders *i.e.* people, groups, or organizations who are likely to affect or be affected (either positively or negatively) by the outcomes of the projects themselves (Freeman, 1984).

On this concern, the identification of the main stakeholders may represent an important step to gather more in depth information about the interest (*alias* "stake") they may have in a particular issue as well as the quantity and type of resources (*e.g.*, financial resources, relevant information, and legitimacy) they can bring to bear on the outcomes of the PV projects.

Depending on the complexity of a given project, there may be a very low or large number of stakeholders who may have different levels of influence or impact on the project that has to be implemented.

As for Palermo Municipality, it is extremely likely that a wide array of stakeholders may have different expectations, strong impact and involvement in what the organization aims to carry out in the matter of sustainable energy.

The potential high number of stakeholders is strictly related to the fact that Palermo Municipality is a public organization and, as such, it is a complex and dynamic system (Bianchi, 2015).

However, not all stakeholders are equal but one may identify, across their entire spectrum, the following categories:

- stakeholders who will be directly or indirectly benefited/affected by the implementation of PV projects (*e.g.*, users, building owners, or the community at large);
- stakeholders who may participate in the implementation of the projects (*e.g.*, investors, and lenders);
- stakeholders who may influence and make decisions regarding the implementation of the projects (*e.g.*, national and/or central government, regulators);
- stakeholders who may not be directly affected by the project development per se but they may have some interest in the project (*e.g.*, environmental organizations).

Particularly, stakeholders may be grouped into two further categories *i.e.* *internal* or *external* stakeholders depending on whether they work within the organization or they operate outside the organization. Although external stakeholders are not part of the organization, they may care about or be affected by the organizational performance and for such a reason they should be taken into account, as well.

As for the ***internal stakeholders***, one may identify the following ones:

- *sectors/departments* of Palermo Municipality directly or indirectly involved in the development and implementation of PV projects (*e.g.*, the environmental department, and the finance department);

- the *employees* who – with their skills, productivity, and commitment – may contribute to the successful development and implementation of PV projects. For instance, investing financial resources in training programs for Palermo Municipality's employees may enhance their knowledge and expertise in the matter of energy efficiency and RES_s;
- the *elected politicians* who have to be in front and inform/communicate to the overall community the benefits arising from the implementation of PV projects. Particularly, politicians may play a crucial role in the budgetary process by diverting financial resources from one sector or intervention area (*e.g.*, school) to another one (*i.e.*, RES_s).

As for the major ***external stakeholders***, one may identify the following ones:

- *PV manufacturers and suppliers* who produce and deliver solar PV panels, respectively. Technological improvements or lower PV prices may stimulate demand for PV systems. At the same time, it may be extremely likely that the installation of PV systems on public buildings owned by Palermo Municipality may positively affect the PV industry in terms, for instance, of green jobs growth;
- *banks and other finance providers* who may provide the needed funds to the Municipality thus making feasible, from a financial viewpoint, the implementation of PV projects;
- *citizens and community at large* who, in the long term, may benefit from direct or indirect advantages associated with higher environmental quality (*e.g.*, better life quality, and higher local area attractiveness) as a result of greater use of sustainable energy for meeting electricity needs;
- *energy service companies (ESCo)* who may provide expertise and funds for PV investments;
- *government and regulators* at local, national, or international level who may affect the development and implementation of PV projects by introducing, for instance, *ad hoc* regulations and legislative frameworks, CO_2 reduction targets, and financial schemes or subsidies;
- *universities* and *schools* that may be involved in initiatives aimed at educating and informing students on issues regarding energy efficiency,

sustainable energy development as well as the main environmental challenges for Palermo Municipality;

- *other community organizations and groups of interest* that may have a strong interest in the implementation of PV projects although not directly involved (*e.g.*, environmental organizations).

As explicitly indicated in the SEAP, Palermo Municipality recognizes how important the involvement of all relevant stakeholders is.

Indeed, a fruitful dialogue with all of the primary stakeholders may enhance organizational transparency.

Based on this, Palermo Municipality aims at promoting initiatives for gathering stakeholders' requests and taking into account them during its strategic planning.

Figure 4.5 illustrates the major internal and external (potential) stakeholders of Palermo Municipality in relation to its PV projects.

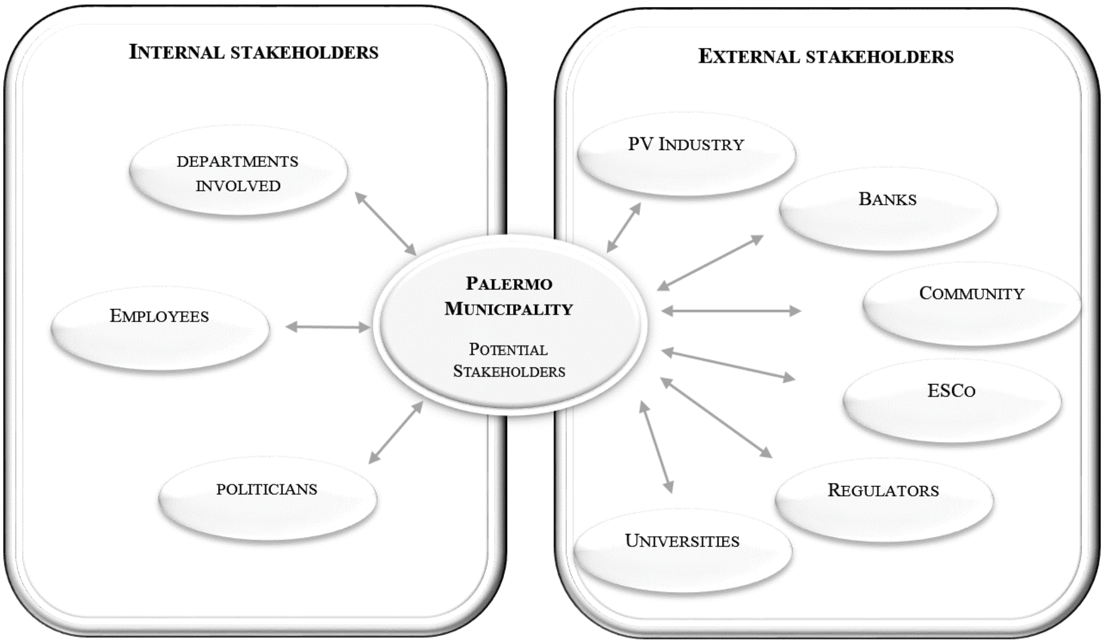

Figure 4.5. Representation of internal and external (potential) stakeholders for PV projects.

4.5. TREND OF PV PROJECTS.

Over the last years, the Municipality of Palermo has recorded a decreasing trend in the number of PV projects implemented (Figure 4.6) although, as already said, it was one of the first Italian local governments to undertake initiatives aimed at promoting the adoption of sustainable energy sources.

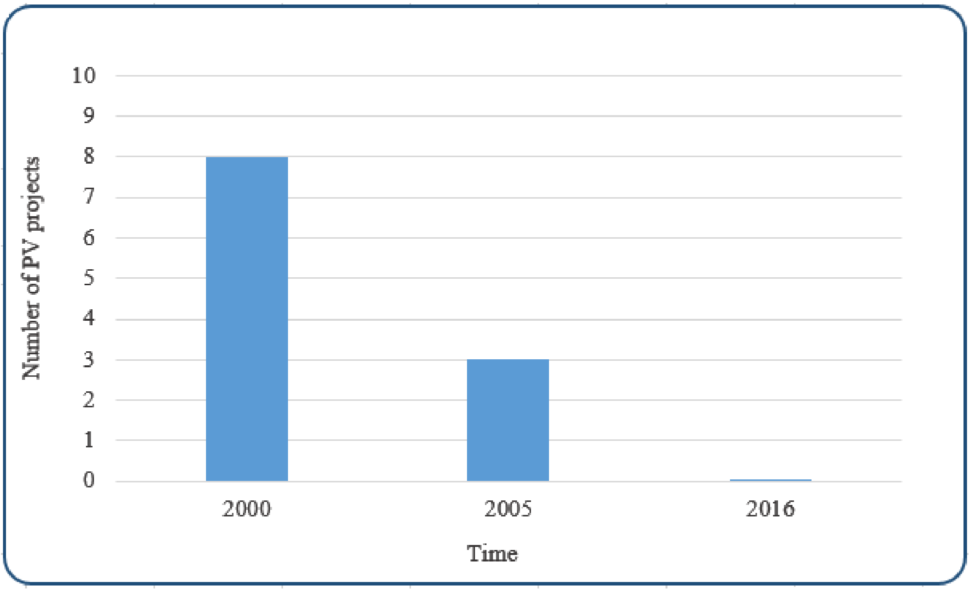

Figure 4.6. Trend of PV projects from 2000 to 2016 (Source: Environmental department of Palermo Municipality).

The trend – portrayed in Figure 4.6 – would let one suppose the presence of some barriers, which have hampered a wider adoption and use of PV systems in the Municipality of Palermo.

Today, the identification of the major barriers – that may continue to hinder the successful implementation of PV projects in upcoming years and, then, the fulfillment of stakeholders' expectations – represents an important step.

On this concern, the SEAP does not provide a comprehensive analysis of the main current (and potential) barriers.

Such an analysis has been carried out by means of interviews and it is presented in the next section.

4.6. ANALYSIS OF THE MAIN CRITICAL ISSUES AFFECTING THE ADOPTION OF PV SYSTEMS[177].

In the Municipality of Palermo, the FIT scheme (*alias* "conto energia") – despite its basic role – was not able to foster PV investments due to some critical issues that still today may represent a brake for their wide development.

Indeed, the adoption of PV systems[178] does not only depend on financial incentive mechanisms but it may be also affected by *the way* public decision-makers operate and *the extent to which* they are aware of the interdependencies between the different organizational areas (*e.g.*, financial, infrastructure, and environmental areas).

Particularly, one of the major critical issues – concerning the adoption of PV systems – relates to the maintenance.

Indeed, Palermo Municipality has paid too little attention to PV maintenance operations, which are adversely affected by two main factors, *i.e.*:

- the burden of bureaucracy that refers to the administrative procedures and time required for issuing a call for public tender[179];
- and the shortage of financial resources to be allocated for covering the maintenance costs for PV systems.

A low attention to PV maintenance operations may translate into lower (or even lack of) green energy production thus jeopardizing the financial and non-financial advantages associated with the adoption of PV systems. That is why one should take into account the entire life cycle stages of PV systems – *i.e.* installation, management, and their (potential) disposal – in order to ensure their long-term operation, their highest productivity over the years[180] and finally the replacement of old PV plants.

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[177] This work is based on an analysis of interviews carried out with the Energy Manager, Engineer A. Mazzon, "Innovation, Communication, Sport & Environmental Area", Municipality of Palermo.

[178] Note that here the term "adoption" does not refer just to the phase of investment but it may also refer to the installation and/or usage of PV systems.

[179] Note that today the public tender still represents the main procedure needed for carrying out PV maintenance operations for PV systems owned by Palermo Municipality.

[180] In 2009, the Municipality of Palermo was involved in an initiative to install PV systems on public school building (Cruillas School located in Palermo). The success of such an initiative – known under the name of "*My Future*" and promoted by Vodafone, Enel, and Legambiente – was also

The partial or total loss of green energy production – which, in turn, translates into lower or lack of electricity bill savings – may lead to other adverse consequences for the Municipality such as, for instance, the risk of fiscal damage (*alias* "danno erariale") whenever PV systems are adopted by making use of public funds. This is one of the reasons why, over the last years, the environmental department of Palermo Municipality decided to not apply for external public funds thus cutting down the development of further PV projects and, then, PV investments.

Based on this, one may envisage the following CLD (Figure 4.7), which illustrates – through causal effect relationships – the implications of low PV maintenance frequency on new PV investments.

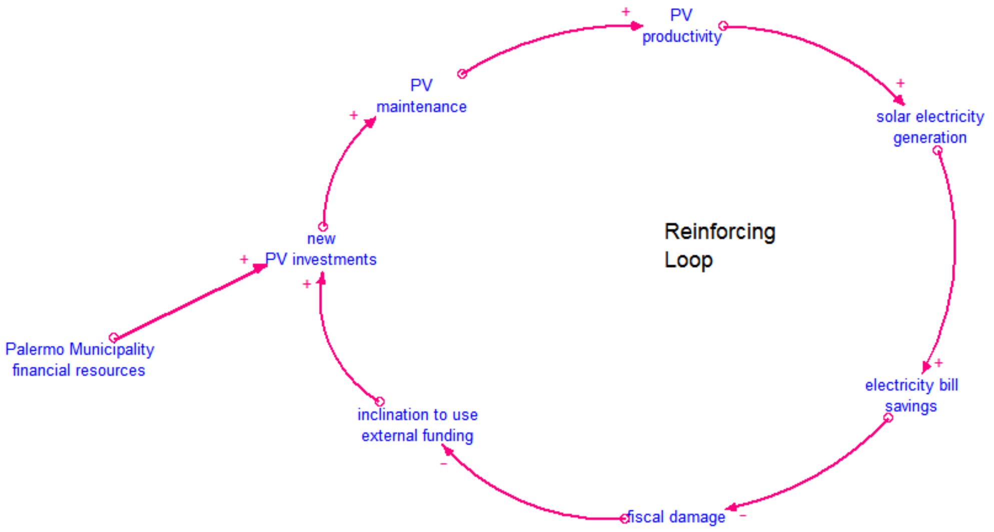

Figure 4.7. Causal Loop Diagram: implications of PV maintenance frequency on new PV investments.

Moreover, PV investments have been negatively affected by the shortage of Palermo Municipality's financial resources although such a difficulty could be overcome by involving the private sector through, for instance, the project financing techniques[181]. In particular, the main financial advantage for private organizations could be related, for instance, to the gain of tariffs provided under the FIT scheme.

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guaranteed by an *ad hoc* obligation. Specifically, Palermo Municipality had to donate FITs to the involved school, which in turn had to use such tariffs to implement PV maintenance operations.

[181] The project finance is "the raising of finance on a limited recourse basis in order to develop a huge infrastructure through a special purpose vehicle that happens to be the borrower and which will have to generate sustainable cash flows to repay debts" (Gardner & Wright, 2014). Available at:

Nevertheless, the private sector has never been involved to financially support PV investments in the Municipality of Palermo but its participation has occurred in a “traditional way” that is by submitting requests aimed at winning public tenders concerning the installation of PV systems.

Notably, difficulties – in involving private organizations as funders – have been (and still are) closely related to even more cumbersome bureaucratic procedures required for the purpose.

Therefore, bureaucratic barriers may exacerbate the problem of shortage of financial resources thus making more and more challenging the PV investments.

Nonetheless, for a deeper understanding of the main critical issues related to the adoption of PV systems, it is not only important to know *how many* financial resources public organizations own but also *how* such resources are allocated among the different projects (or organizational units).

A challenging question could be the following one: “*on what programs or projects shall the Municipality of Palermo spend the public’s money?*” or, alternatively, “*on what basis shall the Municipality of Palermo allocate X euro to project A instead of project B?*”.

Budgetary choices are the result of a process in which different “actors” seek to formulate proposals by taking into account priorities, resource availability, goals to be achieved, and performance data[182].

As for the Municipality of Palermo, one may detect two major dysfunctional behaviors that may have implications for budget allocation for PV systems[183], *i.e.*:

- a prevailing *departmental view* of administration in place of a systemic (or holistic) one;

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http://www.hsbcnet.com/gbm/attachments/products-services/financing/project-finance.pdf. See also Fight, 2005; Gatti, 2013.

[182] The budget process starts with the formulation of proposals coming from each department. Thus, the environmental department submits to the financial department budget forecasts (*alias* estimates) related to new PV projects to be implemented. Once the financial department receives such forecasts, it outlines the annual budget allocation that may or may not accept proposals received by the environmental department. At the end of such a process, the plan is submitted to a representative body (*alias* “Consiglio comunale”) whose approval and authorization are necessary before the plan may be executed.

[183] Indeed, budget forecasts coming from the environmental department usually are not fully taken into account by the financial department – which would tend to cut money – and also by the political level which would not tend to propose budget amendments in favor of PV investments.

- a prevailing *myopic view*, which implies thinking and acting with a short-term focus rather than a long-term one.

As far as the departmental view is concerned, Palermo Municipality decision-makers tend to focus their attention on the most common services/areas (*e.g.*, schools) at the expense of other equally important ones (*e.g.*, development of PV projects). This may generate a trade-off in space.

Therefore, the limited financial resources are mainly allocated for ensuring the provision of such services that, in most cases, are associated with the fulfillment of short-term needs.

As for the myopic view, public decision-makers seek to concentrate their efforts towards those activities or programs that have an immediate effect on citizen satisfaction. For instance, the allocation of financial resources for the development of more innovative garbage collection systems may have a direct positive effect on citizen satisfaction especially if results can be achieved in the short-term. A narrow focus on the short-term horizon may generate a trade-off in time.

Behind such public decision-makers' dysfunctional behaviors there might be the following factors:

- poor awareness of advantages associated with the adoption of PV technology (or more generally RES_s). Indeed, such a technology allows gathering high benefits (*e.g.*, high accumulation of electricity bill savings, high accumulation of CO_2 emissions avoided) over the medium-long term horizon thus going beyond the electoral mandate;
- poor ability to capture synergies and interconnections between different organizational areas. For instance, a narrow focus on education programs ("school, education, and childcare area") rather than on RES_s ("environmental area") may neglect the fact that investing in such resources may generate money (in terms of bill electricity savings) that can be used for improving school services, as well;
- difficulties in measuring non-monetary benefits. Specifically, PV technology may allow achieving – mainly over a long time span – outcomes that are quite hard to measure or quantify since they are intangible (*e.g.*, improvements of environmental quality, local area image, safety, life quality,

health and well-being conditions). Hence, the problematic nature of "*counting the uncountable*" may adversely affect decision-makers' strategic learning process and, then, their budgetary choices. Moreover, difficulties in measuring non-financial benefits may foster the adoption of a tunnel vision of performance;

- (political) sensibility that might be considered not sufficiently enough to translate political intentions into concrete actions for several reasons (*e.g.*, lack or shortage of financial resources for PVs);
- a narrow focus on output measures (*e.g.*, number of PV projects) rather than on outcome ones (*e.g.*, green energy production from PVs);
- the adoption of traditional PM systems that, as already discussed in Chapter 3, tend to manage organizational performance from an overly static viewpoint (in both time and space).

Finally, unintended consequences may also arise if public decision-makers tend to promote efficiency improvements[184] by adopting, for instance, an indiscriminate cost-reducing policy.

Since PV technology usually presents high upfront costs, public policies may not encourage the adoption of PV systems thus allowing the Municipality to bear lower costs and, thereby, contributing to improve its organizational efficiency.

However, such a myopic policy may lead – after a certain delay – to higher costs thus compromising the initial efficiency improvements.

Indeed, the lower inclination to invest in PVs by the Municipality would imply higher costs – in the medium- and/or long-term horizon – in terms of higher electricity bills on the one hand and lack of electricity bill savings on the other. Such an example is depicted in Figure 4.8.

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[184] In the public sector, the greater focus on efficiency improvements has been also the result of the diffusion of a movement known as "New Public Management" (Hood, 1991; Osborne & Gaebler, 1992; Lane, 2000; Barzelay, 2002; Carlin, 2005; Anessi Pessina, 2007).

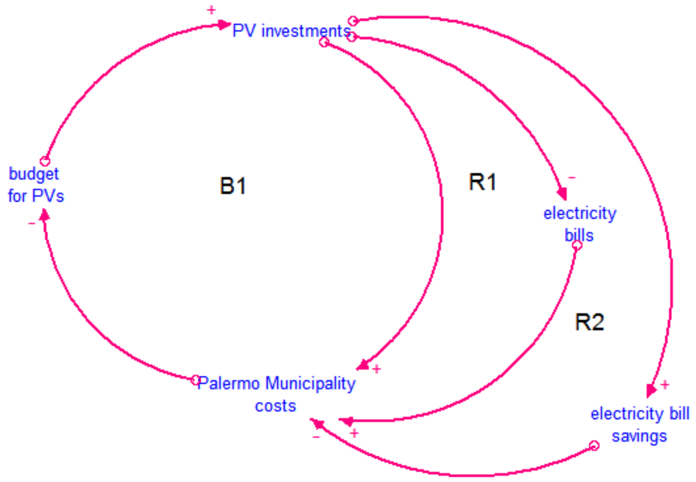

Figure 4.8. Unintended effects of a myopic view based on cost-cutting policy in the short-term.

Although not explicitly illustrated in Figure 4.8, a narrow focus only on efficiency (output measures) may also generate – over a long period of time – poor outcomes as public value transferred to the territory where the Municipality operates (*e.g.*, environmental quality).

As already anticipated in the previous Chapter, sustainable public policies imply the search for consistency between three perspectives *i.e.*, short *vs*. long term (time perspective), a given organizational area *vs*. another one (internal perspective), and the results in financial *vs*. competitive *vs*. social terms (external perspective).

To this end, the adoption of a DPM approach may allow decision-makers to frame and assess performance within the sustainability perspective. The next section illustrates how to apply a DPM methodological framework to Palermo Municipality with reference to the PV sector.

Before that, a representation of the main critical issues affecting the adoption of PV systems in the Municipality of Palermo is provided in Table 4.1.

BUREAUCRATIC BARRIERS	**FINANCIAL BARRIERS**	**OTHER BARRIERS**
• Burden of bureaucratic red tape also *ex post facto* the installation of PV systems (*e.g.*, PV maintenance operations)	• Shortage of financial resources for PVs (both installation & maintenance operations)	• Lack of managerial culture → prevailing compliance-based approach
• Complex bureaucratic procedures in case of private sector involvement for financing PV projects	• No involvement of private sector as funder (*e.g.*, project financing)	• "Low" awareness of advantages associated with RES_s
	• No requests for external public funds → risk of fiscal damage	• Departmental Vision • Myopic view

Table 4.1. Representation of the main critical issues related to PV systems in the Municipality of Palermo.

4.7. THE DESIGN OF A DYNAMIC PERFORMANCE MANAGEMENT APPROACH TAILORED TO PALERMO MUNICIPALITY.

In order to frame the performance of Palermo Municipality, with reference to the PV sector, an *inter*-departmental perspective – in line with a systemic approach – has been adopted.

Particularly, such a systemic approach may allow public decision-makers to better identify the interdependencies between different units belonging to the same organization thus avoiding the shortcomings associated with the adoption of a departmental view.

Firstly, the design of a DPM approach implies the identification of the end-results related to each organizational unit that, in turn, are affected by performance drivers. These latter are usually expressed as ratios between the current state and a target or benchmark value.

Specifically, performance drivers may be affected by the building up or depletion of strategic resources that are systematically linked to each other.

Indeed, there may be interconnections between different strategic resources *e.g.* the stock "*environmental quality*" may lead to a change in the stock "*local image*". Furthermore, the stock "*local image*" may affect other resources such as, for instance, the stock "*cash or liquidity*" meant as the capability of an organization to get funds from different stakeholders (*e.g.*, private organizations, or central government).

As for the interconnections between the different organizational units, these are made explicit by taking into account that the end-results of each single unit may have an impact on the endowment of strategic resources related to another unit. In particular, end-results are modelled as *in*- or *out*-flows that change over time the stock of strategic resources as a result of the strategies or policies implemented by public decision-makers.

Figure 4.9 portrays how to design a DPM approach tailored to Palermo Municipality in order to frame its performance specifically for the PV sector.

In designing the DPM chart (*alias* framework), four processes and their related organizational areas have been identified, *i.e.*:

- the setting of budget for both PV investments and maintenance operations (budget/financial area)[185];
- the drawing up of PV projects and, then, the definition of the capacity to be installed on public buildings (innovation, communication, sport & environmental area, in short "environmental area");
- the implementation of PV maintenance operations (infrastructure area)[186];
- the production of clean/green energy by means of PVs (energy area)[187].

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[185] The political level may also intervene on decisions regarding "*if*" and "*how much*" to invest in PVs.

[186] Note that the process "PV maintenance operation" would be under the responsibility of the "Infrastructure Area" whenever the Municipality would carry it out (internalization). The issue of "internalization *vs*. outsourcing" of PV maintenance is discussed in the next sections.

[187] Actually, the "green energy production" is a process that still refers to the "Environmental Area". However, one has preferred adding another area *i.e.* "Energy Area" just for reasons related to the need to distinguish between two distinct phases *i.e.* the drawing up of PV projects on the one hand and the production of green energy from PVs on the other.

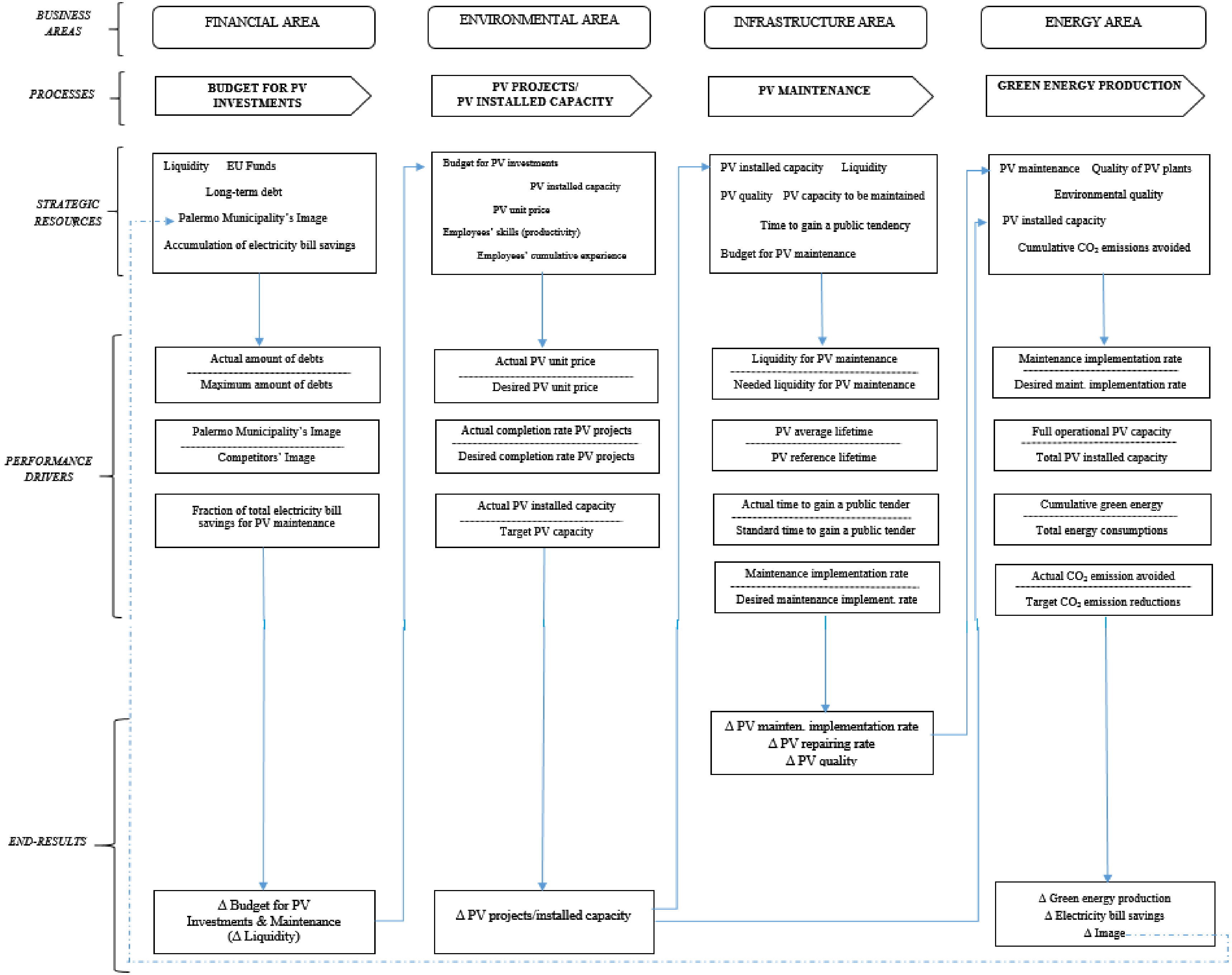

Figure 4.9. The DPM framework to frame Palermo Municipality's performance related to the PV sector.

The design of the above framework started from the identification of the main end-results related to each unit and proceeded with the identification of the major interdependencies between such organizational units.

As for the financial area, changes in budget for PV investments and PV maintenance operations have been considered the main end-results, which may be influenced by the three following performance drivers:

1. actual amount of debts/maximum amount of debts;
2. Palermo Municipality's Image/Competitors' Image that, in turn, affects the average private funds attractiveness;
3. fraction of total electricity bill savings for PV maintenance.

To affect the above-listed performance drivers, the following strategic resources have been identified: long-term liabilities, EU funds, Palermo Municipality's image, accumulation of electricity bill savings and liquidity.

As regards the environmental area, change in installed PV capacity has been considered the major end-result. Specifically, it would depend on the following performance drivers, namely:

1. actual PV unit price/desired PV unit price, which may directly affect the change in PV capacity installed;
2. actual time for PV projects/desired time for PV projects;
3. actual PV capacity installed/target PV capacity to be installed.

Again, performance drivers may influence end-results only through their strategic resources.

Therefore, strategic resources needed to improve the performance related to the environmental area may be the following ones: budget for PV investments, installed PV capacity, PV unit price, employees' skills (productivity) as well as employees' cumulative experience.

Notably, the first above-mentioned strategic resource *i.e.* "budget for PV investments" changes over time through its corresponding end-result "change in budget for PV investments", which – as already said – represents the main end-result of the financial area.

Thus, the interdependencies between the financial and environmental areas have been made explicit, consistently with the need to adopt an *inter*-departmental perspective to frame the performance of Palermo Municipality.

The same line of reasoning may be applied to the other two organizational areas. Indeed, PV capacity installed – whose end-result comes from the environmental area – represents one of the main strategic resources of the infrastructure area. The other relevant resources are budget for PV maintenance (liquidity), quality of PV plants, PV capacity to be maintained, and time to gain a public tender.

In particular, the above strategic resources may affect the three main end-results – *i.e*. change in PV maintenance implementation rate, change in PV repairing rate and change in PV quality – through the following performance drivers:

1. liquidity for PV maintenance/needed liquidity for PV maintenance, which may specifically affect the first two above-mentioned end-results;
2. average PV lifetime/reference PV lifetime;
3. actual time to gain a public tender/standard time to gain a public tender, which may primarily influence the change in PV maintenance implementation rate;
4. actual maintenance implementation rate/desired maintenance implementation rate, which may have an impact on the change in quality of PV plants meant as PV module efficiency.

Finally, the stocks "PV capacity installed" (environmental area), "PV maintenance" (infrastructure area) and "PV plants quality" (infrastructure area) represent – together with the stocks "environmental quality" and "cumulative CO_2 emissions avoided" – the main strategic resources that determine changes in the end-results of the last organizational area *i.e*. the "energy" one.

Specifically, such a change is made possible through the identification of the major performance drivers, namely:

1. maintenance implementation rate/desired maintenance implementation rate;
2. full operational PV capacity/total PV capacity installed;
3. cumulative green energy/total energy consumptions;
4. actual CO_2 emissions avoided/target CO_2 emission reductions.

The above performance indicators may affect the change in green energy production that, in turn, may have an influence on both the change in electricity bill savings and the change in Palermo Municipality's image.

Finally, the end-result "change in Palermo Municipality's image" affects the endowment of its strategic resource "Palermo Municipality's image", which is included in the column "financial area" since it may affect the private funds attractiveness for new PV investments[188].

4.8. INFORMATION SOURCES FOR MODELING THE PV SECTOR.

In order to understand the dynamics of the system under analysis and, then, to model its structure, an important source of information is represented by data stored mentally in people's heads, known as "mental database".

Forrester (1980) identifies three types of data needed for developing the structure of the system: mental, written, and numerical databases.

Mental database, as said before, spans all the non-documented information in people's mind, based on observation and experience (Snabe, 2007).

Written database includes also important information about the system structure, which is usually stored in reports, archival materials, and organizational charts[189].

Finally, *numerical database* – containing the familiar time-series and data on some parameters – provides just a tiny part of all information needed for the modeling process.

Moving down from mental to numerical database, there is indeed a progressively decrease of information about the structure of the system (Figure 4.10).

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[188] Such a concept is better explained in Section 4.9.

[189] Note that the written record presents two major shortcomings: it cannot be queried and it has been already filtered through the perceptions and purposes of the writer (Forrester, 1992).

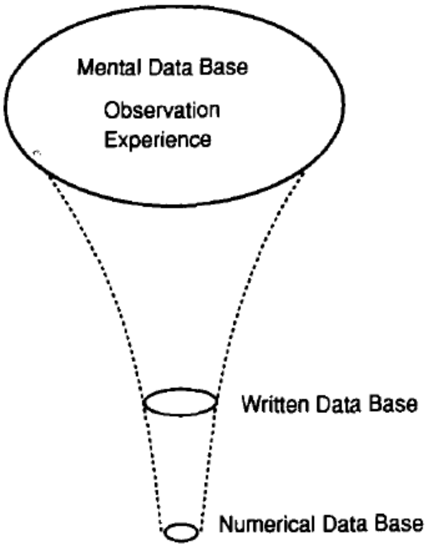

Figure 4.10. Mental database and decreasing content of written and numerical databases (Source: Forrester, 1992, p. 56).

Particularly, information for modeling the PV sector of Palermo Municipality mainly comes from mental, written databases (*e.g.*, SEAP report, and operating procedures) and to a lesser extent from numerical databases (*e.g.*, Istat database).

In retrieving information from mental databases, among the different techniques and methods suggested in SD literature for knowledge elicitation[190], semi-structured interviews have been carried out by involving people working inside the organization (specifically, the environmental and financial areas of Palermo Municipality).

Interviews have allowed one a better understanding of the cause-to-effect direction between variables (*i.e.* internal causality) as well as gaining data on some parameters.

However, in developing the quantitative model, the estimation of some parameters and variables may suffer from the lack of explicit or accurate data. This is particularly true for the so-called “soft variables” that – unlike “hard variables” – are tricky to measure since numerical data is rarely available.

For instance, it is not that easy to find an accurate value for intangible variables such as *environmental quality* or *local area image*, which are the result of perceptions or expectations by citizens or, more generally, by community.

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[190] See Willard & Trimble (1992); Vennix (1996); Luna-Reyes & Andersen (2003).

Given the difficulties in finding an accurate value for such variables, some modelers tend to include into their models just those variables for which numerical data and quantitative metrics are available while they tend to neglect the soft variables.

However, “omitting such variables is equivalent to saying they have zero effect, probably the only value that is known to be wrong” (Forrester, 1961: 57).

For such a reason, in modeling the PV sector of Palermo Municipality, a number of soft variables – considered important for the insights they might yield into the dynamics of the system – have been taken into account alongside with the hard variables.

Measurement of soft variables – included into the quantitative model – has been mainly based on an analysis of data collected during the different interviews and use of proxy variables.

4.9. CAUSAL LOOP DIAGRAM.

As already introduced in Chapter 3, the CLD is a useful tool for representing the main feedback loops responsible for a given problem (Sterman, 2000).

Starting from the formulation of hypotheses and insights emerging from a critical (thematic) analysis of interviews, cause-and-effect relationships between variables have been elicited at first[191].

Afterwards, the main feedback loops have been identified and mapped.

Figure 4.11 portrays seven reinforcing (R) and four balancing (B) feedback loops that one believes be responsible for the dynamics of the PV sector in the Municipality of Palermo[192].

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[191] Note that hypotheses have been also formulated based on information contained in written documents (*e.g.* SEAP of Palermo Municipality).

[192] The CLD has been developed with Vensim software.

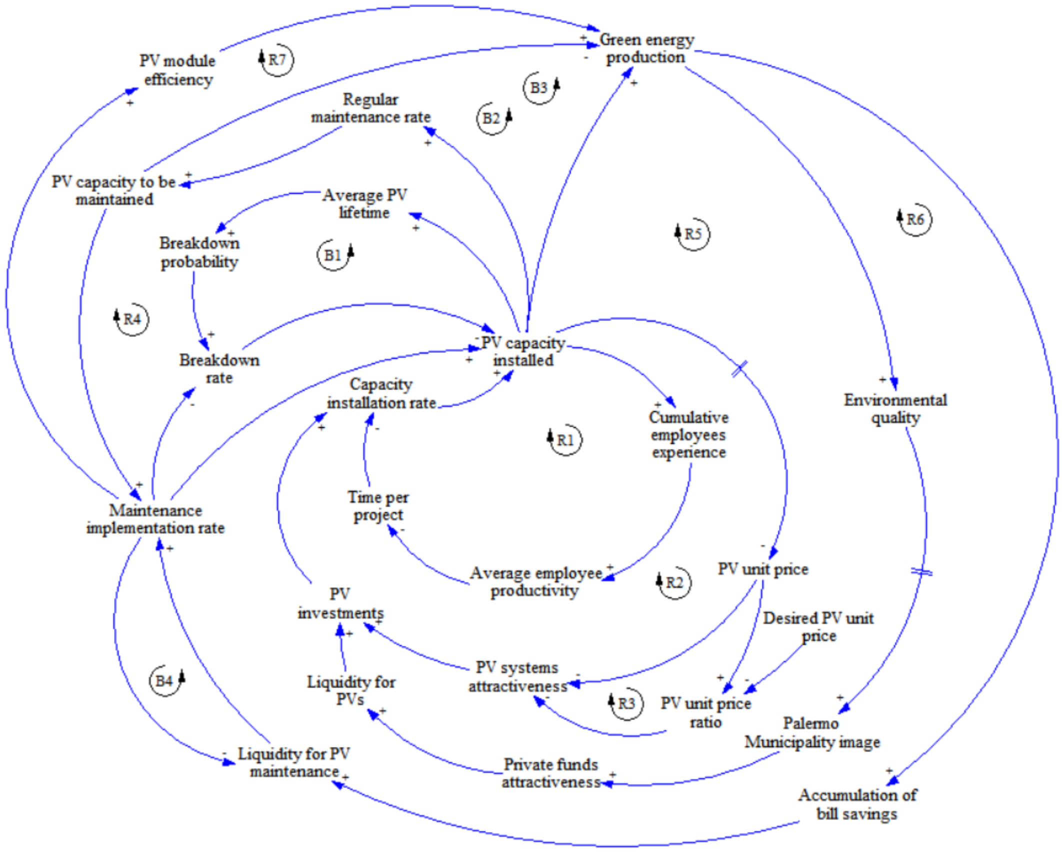

Figure 4.11. Causal Loop Diagram for the PV sector.

R1 loop would depict the "learning by doing" principle: higher installed PV capacity would determine – *ceteris paribus* – higher employees' experience, wherein this latter one is measured in terms of average productivity. Thanks to their knowledge (expertise) acquisition, employees may be able to develop further PV projects in less time thus allowing Palermo Municipality to install more PV capacity given a certain threshold (*alias* budget) for PVs. Conversely, the higher the time employees spend for developing PV projects, the lower the new installed PV capacity will be.

R2 loop shows how an increase of installed PV capacity may cause, over time, a reduction of PV price (cost) mainly thanks to the development of the PV industry[193]. Thus, Palermo Municipality – given its yearly budget for PVs – will be able to install more PV capacity as a result of the price reduction.

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[193] Indeed, such a hypothesis comes from information contained in the SEAP of Palermo Municipality (specifically, section devoted to "Action 1.17"). Here, among the potential benefits arising from the installation of PV plants on public buildings, the SEAP also envisages the

Like the previous reinforcing loop, R3 still represents the dynamics of the PV price though under a different perspective. Here, the actual PV price, which – as already said – is affected by the installed PV capacity, is compared to a desired one. Whenever the first one is higher than the second one, one may expect that the inclination to invest in PVs goes down thus determining a reduction of new PV capacity[194] installed.

R4 loop shows how regular (preventive) PV maintenance – that, in turn, depends on the stock of installed PV capacity – affects the breakdown rate. Indeed, the implementation of regular PV maintenance operations may allow Palermo Municipality to prevent the risk of PV panel breakdowns in the future. Moreover, the occurrence of PV panel breakdowns may compromise the full operation of PV capacity at least until they will be repaired.

R5 loop shows how higher installed PV capacity would result into higher green energy production that, in turn, allows avoiding larger CO_2 emissions thus leading to – other conditions being equal – environmental quality improvements. After a certain delay, it is likely that environmental quality improvements may contribute to enhance Palermo Municipality's local image as perceived by the community at large. Finally, improvements in local area image may increase the attractiveness of private funds for new PV investments[195].

R6 loop represents the dynamics by which an increase of PV capacity would determine an increase of green energy production and, then, an increase of electricity bill savings, which might be indirectly used for implementing PV maintenance[196]. Finally, the higher PV maintenance rate – made possible thanks to the availability of liquidity for maintenance – will positively affect the stock of (full operational) PV capacity.

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development of PV industry in terms of technological improvements and then reduction of PV installation costs.

[194] To some extent, this loop would represent the "law of demand": when PV price increases, the demand (*alias* PV capacity to be installed) decreases.

[195] Note that such a feedback loop is based on two main hypotheses. The first one refers to the causal relationship between "renewable energy sources/environmental quality" and "local image" (see SEAP, p. 9) whereas the second one relates to the fact that Palermo Municipality intends to involve private investors (*e.g.*, ESCo) for financially support PV investments.

[196] Actually, the assumption to use electricity bill savings for carrying out PV maintenance represents a policy option, which is discussed in the next sections.

The last reinforcing loop *i.e.* R7 is closely linked to the previous one. Indeed, as already stated, higher green energy production leads to higher electricity bill savings and, then, *ceteris paribus*, higher PV maintenance. The implementation of PV maintenance operations will positively affect the PV module efficiency, which, in turn, represents an important parameter affecting the green energy production rate.

B1 loop shows the effect of average lifetime of PV plants on breakdown rate (or failure rate). Such a causal relationship is positive or direct: the higher the PV plant age is, the higher the probability to breakdown will be.

B2 and B3 loops are closely linked to each other since both of them show the effects associated with a low PV maintenance implementation rate. Once again, the starting point is represented by the installed PV capacity. In fact, when the stock of PV capacity increases, the regular maintenance rate will grow thus leading to an increase of "PV capacity to be maintained". However, a greater stock of "PV capacity to be maintained" may translate – other conditions being equal – into a lower green energy production that, in turn, may cause other effects:

- lower environmental quality, lower local image, lower private funds attractiveness and finally lower (new) PV capacity (B2 loop);
- lower bill electricity savings, lower PV maintenance budget and then lower (full operational) PV capacity (B3 loop).

Finally, B4 loop represents the dynamics of liquidity for PV maintenance. An increase of liquidity may allow Palermo Municipality to carry out more frequently PV maintenance operations that, in turn, will determine a decrease of liquidity once financial resources are used for such a purpose.

To conclude, the CLD – as presented here – has provided the basis to develop the S&F model, which is discussed in the next section.

4.10. STOCK AND FLOW MODEL.

In order to yield additional insights into the dynamics of the PV sector, a S&F model has been built by making use of a modeling and simulation software named “Ithink”.

The quantitative model has been developed by taking into account both the DPM chart and the CLD – already presented in the previous sections – as starting points:

- the DPM chart enabled the identification of the major end-results, performance drivers, and strategic resources to be included into the model, here represented as *in*- or *out*-flow variables, auxiliary variables, and stock variables, respectively;
- whereas the CLD, including the main reinforcing and balancing feedback loops, provided the basis to denote the causal influences among the identified variables.

As for this case study, the quantitative approach has been adopted for developing a learning environment based on a foresight modelling meaning that the aim is not to reproduce a past behavior (reference mode) but rather to simulate possible scenarios (*i.e*. “scenario analysis”).

The quantitative model consists of four main sectors, *i.e*.:

- sector 1 representing the financial dynamics;
- sector 2 portraying the dynamics related to the installation of (new) PV capacity;
- sector 3 showing the dynamics of PV maintenance operations;
- finally, sector 4 representing the dynamics of green energy production, which may affect – either directly or indirectly – three main end-results (outcomes) *i.e*. changes in bill savings accumulation, environmental quality and image.

Firstly, the installation of new PV capacity on public buildings depends on the availability of funds.

Once the financial resources have been allocated to PV systems, the development of PV projects – that represents the preliminary step before installing the PV modules – may take place. Note that, among the different funding sources and financial incentive mechanisms, the FIT scheme cannot be considered anymore since, as already said, it ceased to be applied in 2013.

Based on this, the model starts the simulation by taking into account the financial resources that have been allocated for improving energy efficiency of public school buildings owned by Palermo Municipality[197]. These resources – together with (potential) additional private funds – represent the "*yearly budget for PVs*" that is a variable directly linked to the "*cost installation rate*" that, in turn, affects the "*capacity installation rate*". These two latter flows are represented into the model by using the coflow structure[198]; a simplified version is given in Figure 4.12.

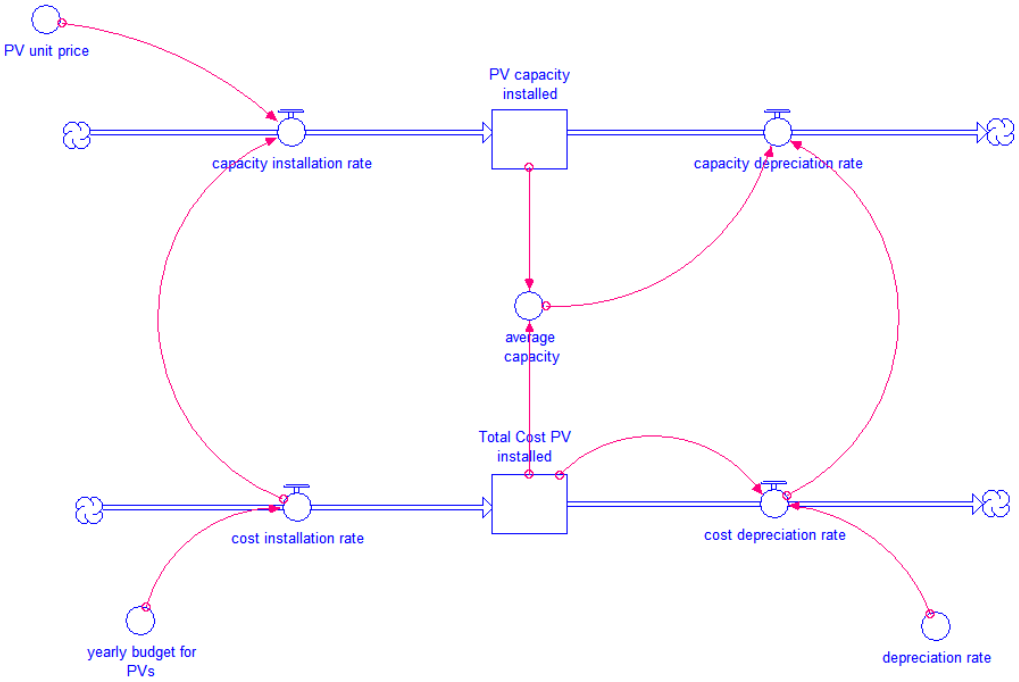

Figure 4.12. Simplified version of the coflow structure for the installed PV capacity.

As Figure 4.12 shows, the "*capacity installation rate*" depends on the amount of available funds for PVs on the one hand and the level of "*PV unit price*" on the other.

In the full version of the model, PV unit price has been modelled as a stock variable that may change over time as an effect of the *"PV capacity installed*"

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[197] Note that such a project (and its allocated financial resources) is part of the "*National Operational Programme (NOP 2014-2020*)" - ("PON Città di Palermo"). This project is identified with the code "PA 2.1.1. C" and its implementation is expected to get started in 2017.

[198] Coflow structures "are used to keep track of the attributes of various items as they travel through the stock and flow structure of the system" (Sterman, 2000: 498). Therefore, "cost installation rate" and "capacity installation rate" have different units of measure *i.e.* "euro/year" and "kW/year", respectively.

compared to the "*PV capacity target*" (*i.e.* the capacity that Palermo Municipality wishes to install on its public buildings in upcoming years[199]).

Going into more detail, the capacity installation rate is also affected by the time employees[200] spend for developing PV projects[201]. Here, it is important to clarify that the model does not take into account (potential) changes in the number of human resources in relation to the number of PV projects to be developed. Indeed, as explicitly stated in the SEAP, Palermo Municipality does not aim at hiring new staff but rather at *re*-training its current employees[202] through *ad hoc* training programmes.

Once PV capacity is installed by making use of available funds, PV maintenance operations should take place to ensure both long-term operation and high performance of PV panels.

Notably, one may identify two types of PV maintenance operations, both of them embodied into the model:

- ***regular (preventive) maintenance*** that consists of general inspections carried out at regular intervals (usually every six months) to *clean* PV panels in order to maximize their efficiency, to *identify* existing problems or to *prevent* future ones;
- ***corrective maintenance*** that aims at *repairing* failed equipment or components (*e.g.*, inverter) to return PV systems back to operation. Usually, the breakdown probability is quite low and it may be affected by two variables: the "*regular maintenance implementation*" and the "*average lifetime of PV modules*".

A particular remark is due to better explain how PV maintenance does work. Indeed, there may be a difference between the scheduled PV maintenance (*alias* the PV maintenance that should be done) and the PV maintenance implemented since this latter one may not take place (or take place just partially) for several reasons, firstly the lack (or shortage) of available funds. For such a reason, in the model,

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[199] Such a dynamic hypothesis has been already discussed in the previous sections.

[200] These are the employees working in the "Environmental Area".

[201] Indeed, as already said, the development of PV projects represents a preliminary step before installing PV modules on public buildings.

[202] See SEAP, Action 1.17, p. 106.

four distinct flows have been included *i.e.* "*regular maintenance rate*", "*breakdown rate*", "*regular maintenance implementation rate*" and "*repairing rate*" (Figure 4.13). These latter two are affected by the amount of available financial resources. Thus, the lack (or shortage) of funds may translate into lack (or lower) PV maintenance implementation and repairing operations.

Moreover, another constraining factor – for carrying out PV maintenance at regular intervals – may be represented by the time needed to implement it, which tends to be quite long (even more than 1 year) due to bureaucratic red tape associated with the issuing of public tenders.

Figure 4.13 portrays a simplified version of the PV maintenance dynamics.

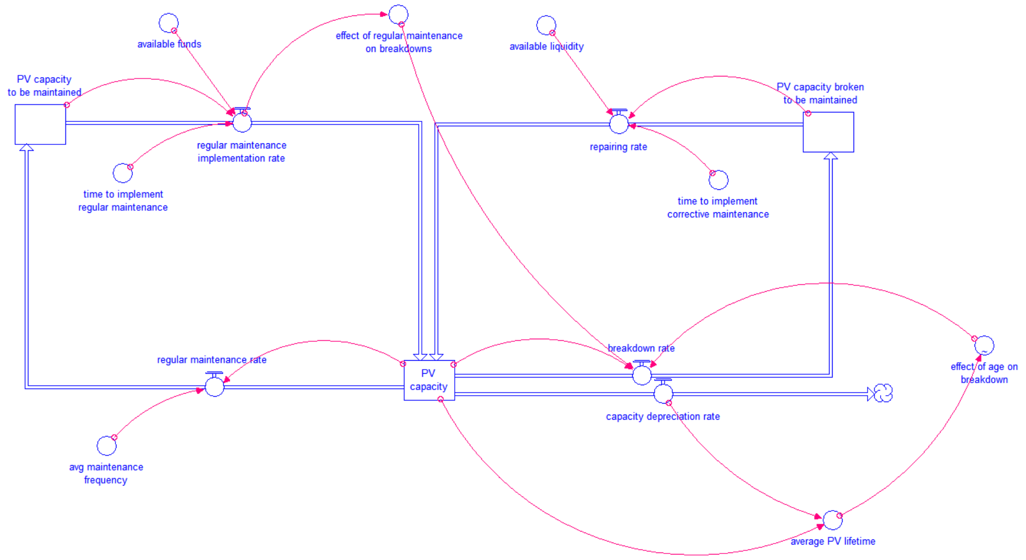

Figure 4.13. Simplified version of the PV maintenance dynamics.

Periodic inspections, scheduled preventive maintenance and corrective actions are very critical factors for the successful operation of a solar PV system and they become more and more important as the system gets older.

Indeed, PV maintenance carried out at a very low frequency (or even no PV maintenance at all) may jeopardize most of (or even all) the benefits associated with the adoption of PV systems in terms of economic viability, performance, and green energy production.

Based on this, "*green energy production*" has been modelled as a stock variable, which is affected by the following factors (Figure 4.14):

- the "*full operational PV capacity*" that represents the total installed PV capacity minus the PV capacity that still has to be repaired or maintained;

- the “*average electricity production*” for each kWp installed;
- the parameter “*module efficiency*” that, in turn, depends on other variables such as its “*standard or normal value*”, the “*potential losses*” and finally the “*effect of PV maintenance implementation rate*” on module efficiency[203].

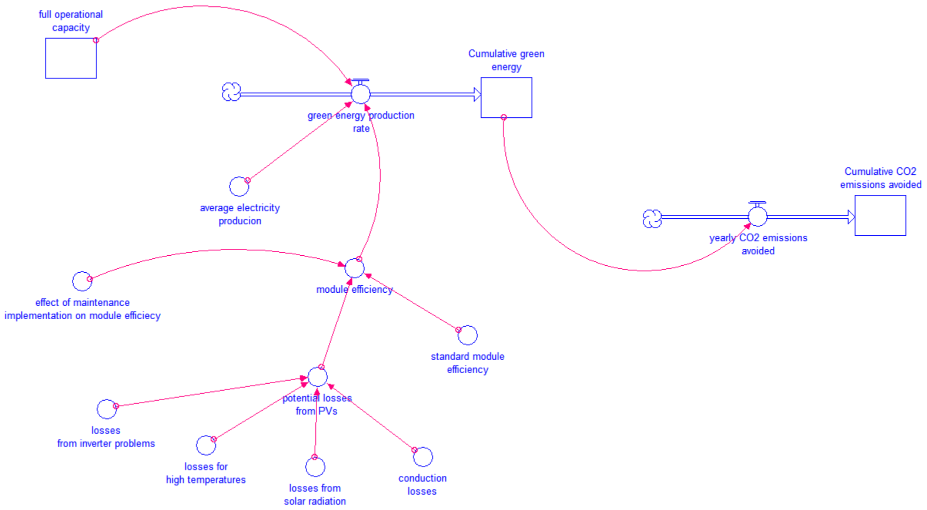

Figure 4.14. Simplified version of green energy production dynamics.

Finally, green energy production represents a key-factor for fostering the achievement of outcomes in terms of “*electricity bill savings*” (financial performance), “*environmental quality*” (social performance) and “*local area image*” (competitive performance).

Figure 4.15 portrays the main end-results affected – either directly or indirectly – by the rate of green energy production.

Figure 4.15. End-results affected by the green energy production rate.

Moreover, the accumulation of electricity bill savings may represent an input variable for the “yearly budget for PV maintenance” thus affecting the rate of PV maintenance implementation. Likewise, an improvement of local image – which,

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[203] Note that the calculation of “module efficiency” could be much more complex from an engineering viewpoint. However, for the purpose of this research study, some (more) simplified assumptions have been introduced in order to calculate such a parameter. Thus, for instance, potential losses have been defined by considering just four exogenous variables *i.e.* losses from inverter problems, losses for high temperatures, losses from solar radiation and finally conduction losses.

in turn, is affected by the environmental quality – may affect the attractiveness of private funds to be invested in PV systems.

To conclude, the S&F model has represented a useful tool for better understanding the dynamics of the system under investigation; its full version is provided in the Section under the heading “Appendix B” while model equations are provided in “Appendix A”.

4.11. DISCUSSION OF POLICY OPTIONS AND SIMULATION RESULTS.

The S&F structure – as already presented in the previous section – represents the basis for simulating possible policy options and, then, discussing the resulting behaviors.

Simulating alternative scenarios may allow enhancing public decision-makers’ strategic learning processes with a view to achieving sustainable development in the long run.

Starting from the main critical issues affecting the adoption of PV systems in the Municipality of Palermo, some alternative policy options have been formulated and tested through computer simulations.

However, before discussing the first policy option, it may be useful to see how the model structure behaves under the basic scenario *i.e.* with no policy in place. Such a first situation envisages as follows[204]:

- use of external funds (*i.e.* NOP financial resources) for financing PV investments;
- lack of financial resources for carrying out PV maintenance operations.

By running the model structure under the above conditions, the following main patterns of behavior have been obtained[205]:

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[204] This first case would show what could happen whenever past conditions (or critical issues) would continue to persist in the future without adopting any lever of intervention. Notably, critical issues are those already mentioned and discussed in Section 4.6.

[205] Note that the length of simulation goes from 2017 to 2038 (DT= 0.25). It could appear a quite long time for simulating future scenarios but one should take into account that the average lifespan of PV plants may be even far longer than 20 years.

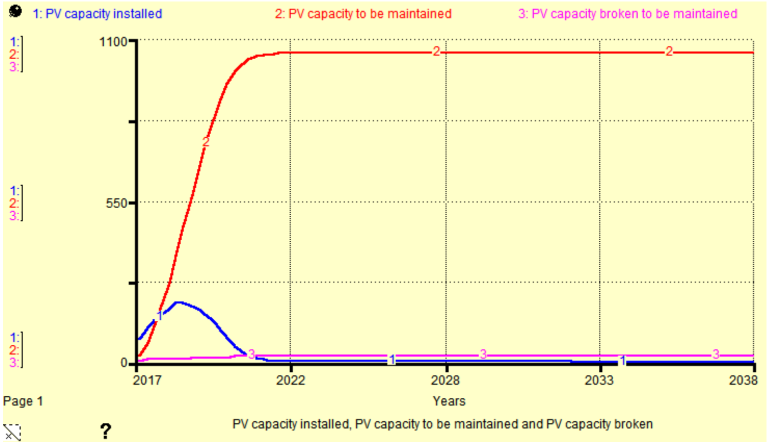

Figure 4.16. Behavior of (full operational) PV capacity installed, PV capacity to be maintained, and PV capacity broken (stock variables) with no policy.

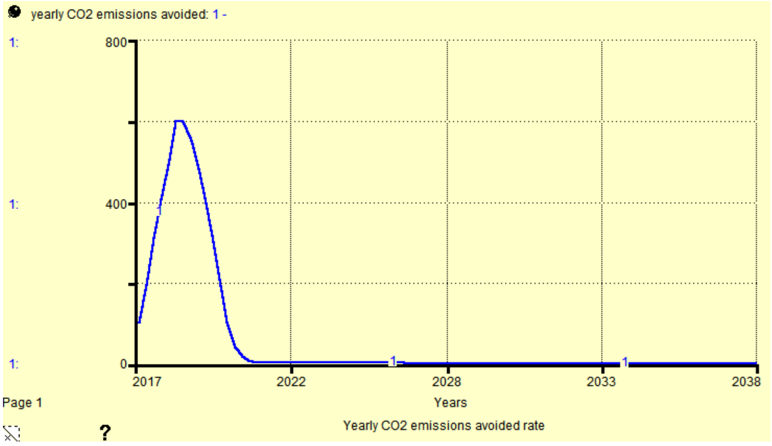

Figure 4.17. Behavior of CO_2 emissions avoided rate (flow variable) with no policy.

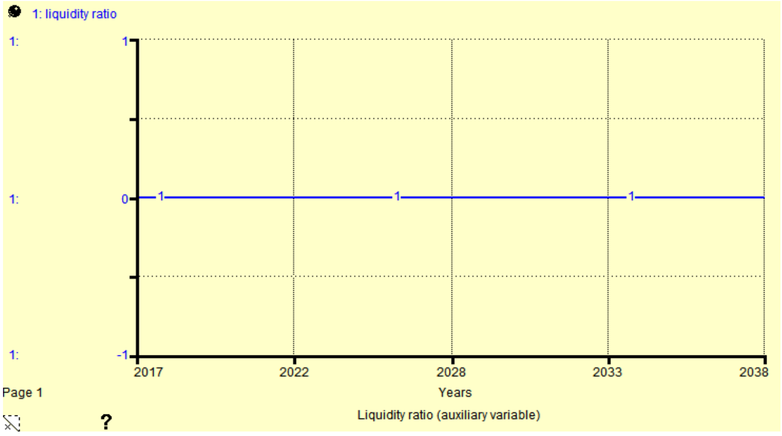

Figure 4.18. Behavior of liquidity ratio (auxiliary variable) with no policy.

The above graphs would depict an *unsustainable (extreme) situation* in the long term, which calls for some (recovery) policy in order to counteract adverse consequences.

As Figure 4.16 shows, the behavior mode of (full operational) installed PV capacity is similar to that of "*overshoot and collapse*" (Sterman, 2000): it initially increases – thanks to the use of (NOP) funds – up to reach a peak of 198 kW in 2019 and afterwards it starts going down until it gets value zero in later years (see blue line).

The decrease of (full operational) installed PV capacity is not only due to the cessation of available funds from 2020 onwards[206] but it is also strictly related to the behavior of its two other inflows *i.e.* "*maintenance implementation rate*" and "*maintenance repairing rate*"[207]. Indeed, these two inflow variables get value zero for the entire simulation length due to the lack of financial resources (*alias* budget) for PV maintenance operations. That would explain why the liquidity ratio – that is given by the "yearly budget for PV maintenance/needed liquidity for PV maintenance" – is always equal to zero (Figure 4.18).

Therefore, "*maintenance implementation rate*" and "*maintenance repairing rate*" – equal to zero – generate an increase of their related stocks of "*PV capacity to be maintained*" and "*PV capacity broken*"[208], which initially grow and afterwards reach an equilibrium just when the installed PV capacity drops to zero (Figure 4.16).

Once the stock of (full operational) installed PV capacity starts decreasing because of no PV maintenance operations, other important end-results – which are directly or indirectly affected by such a stock – start going down as well.

For instance, this is the case of "*green energy production rate*" and "*yearly-avoided* CO_2 *emission rate*" (Figure 4.17), which initially go up and afterwards go down until they get value zero.

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[206] Indeed, according to the current knowledge, NOP resources will be available just for a limited period (*i.e.* from 2017 to 2020); that is why the "*capacity installation rate*" gets value zero from 2021 onwards. Under this first basic scenario, other financial resources for installing new PV capacity are not taken into account but rather the model just embodies those financial resources that have already been allocated for improving energy efficiency.

[207] To this end, it may be helpful to have a look at Figure 4.13 again.

[208] Note that "*maintenance implementation rate*" and "*maintenance repairing rate*" represent outflow variables for the stocks of "*PV capacity to be maintained*" and "*PV capacity broken*", respectively and, at the same time, they are inflow variables for the stock of (full operational) PV capacity installed.

Briefly, such a first scenario with no policy implemented would denote the potential side effects that might arise whenever:

- interrelationships between different organizational units or areas – as already shown in the DPM chart – are not properly taken into account when designing and implementing public policies[209] concerning PV systems (*i.e.* lack of a systemic view);
- and a narrow focus on the short-term horizon is taken, as well (*i.e.* myopic view). In this sense, the design and application of a DPM approach – through computer simulations – may allow public decision-makers to overcome the adoption of a myopic view[210].

Indeed, as for the last point, it is not sufficiently enough to finance PV investments in the short-term but it is also important to ensure high PV system performance in the medium/long-term horizon through, for instance, the implementation of PV maintenance operations.

Based on this, a policy has been formulated and tested through simulation runs. Such a first policy option envisages the use of electricity bill savings for PV maintenance thus trying to overcome the problem of lack (or shortage) of needed liquidity to be allocated for the purpose[211].

The S&F model structure added for testing such a first policy option is portrayed in Figure 4.19 (simplified version).

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[209] See Bivona & Montemaggiore, 2010.

[210] For instance, as Figure 4.17 shows, the yearly-avoided CO_2 emissions increase in the short-term. However, in the long-term, they drop to zero. Therefore, a narrow focus on the short-term horizon would not allow public decision-makers to capture such a "change of direction".

[211] Note that such a policy option has been shared and discussed with the key-actors of both "Environmental" and "Budget/Financial" areas. In particular, the use of electricity bill savings for fulfilling other "needs" (in this case, PV maintenance) recalls the way ESCOs operate. Indeed, these companies provide energy services to final energy users (both private and public ones), including the supply and installations of energy efficient equipment. They can finance or arrange financing for the operation and their remuneration is directly tied to the energy savings achieved. See *http://iet.jrc.ec.europa.eu/energyefficiency/esco*.

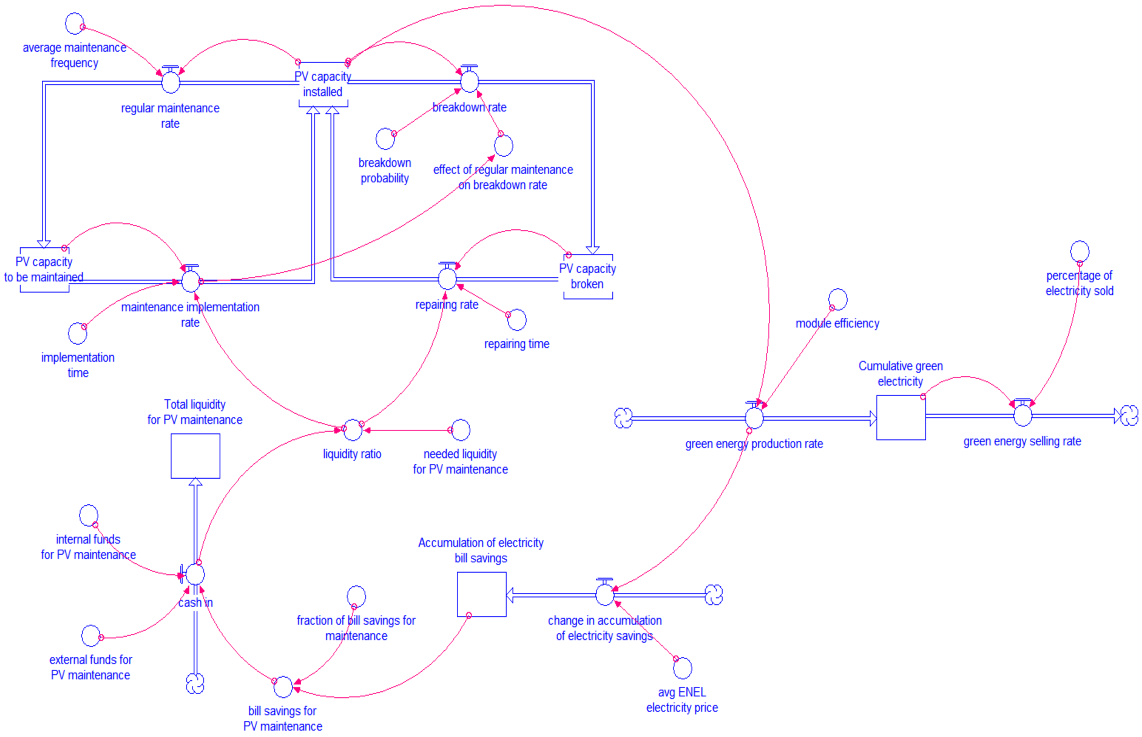

Figure 4.19. Stock & Flow structure for policy option 1 (simplified version).

This first policy option – corresponding to the second scenario – has been tested under the following conditions:

- use of external funds (NOP resources) for financing the installation of new PV capacity, like the first basic scenario discussed earlier;
- fraction of electricity bill savings – to allocate for PV maintenance operations – equals to 40% of the total amount[212];
- a quite long time to implement regular PV maintenance due to bureaucratic red tape (1 year).

By running the model structure under the above conditions, the following main patterns of behavior – which are compared to the ones associated with the first scenario (see first/blue line) – have been obtained:

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[212] From the interviews, one has found out that there is not an obligation to allocate the entire amount of electricity bill savings for financing or supporting PV ("*assenza di vincolo di destinazione*") but rather the fraction of bill savings that may be allocated for PVs is indeed decided at the political level. Here, the assumption is that just the 40% of total electricity bill savings is allocated for financing PV maintenance operations.

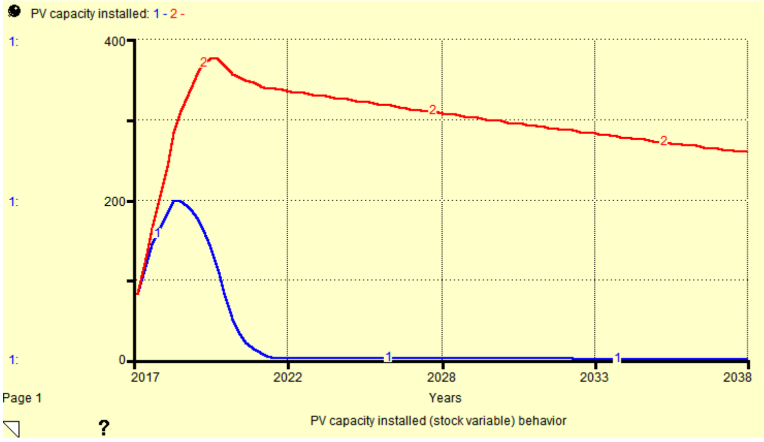

Figure 4.20. Behavior of (full operational) PV capacity with no policy (blue line) and first policy option (red line).

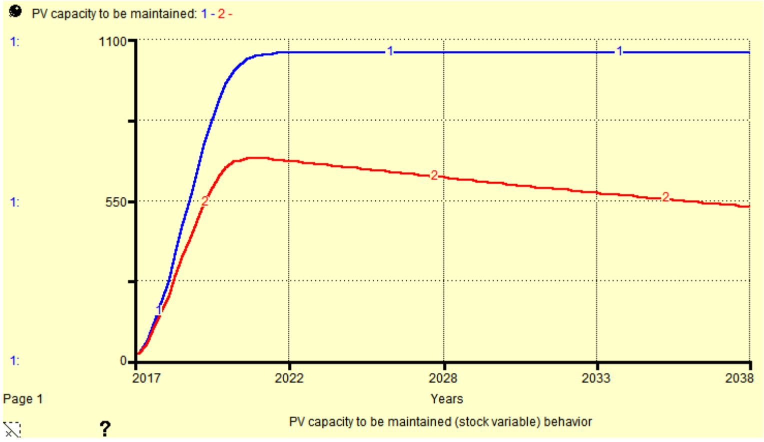

Figure 4.21. Behavior of "PV capacity to be maintained" with no policy (blue line) and first policy option (red line).

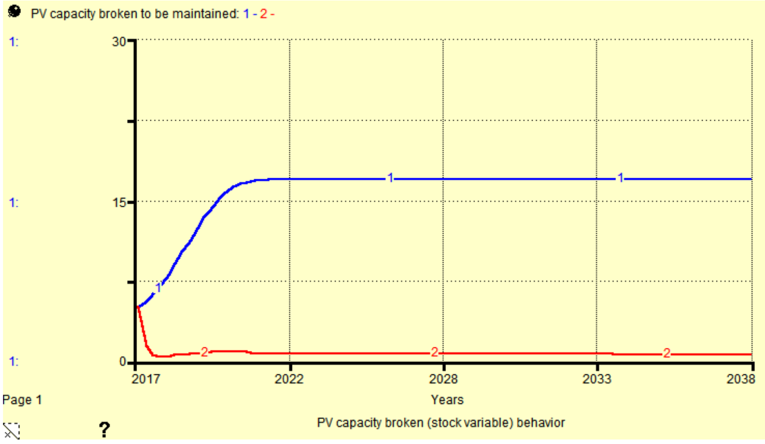

Figure 4.22. Behavior of "PV capacity broken to be maintained" with no policy (blue line) and first policy option (red line).

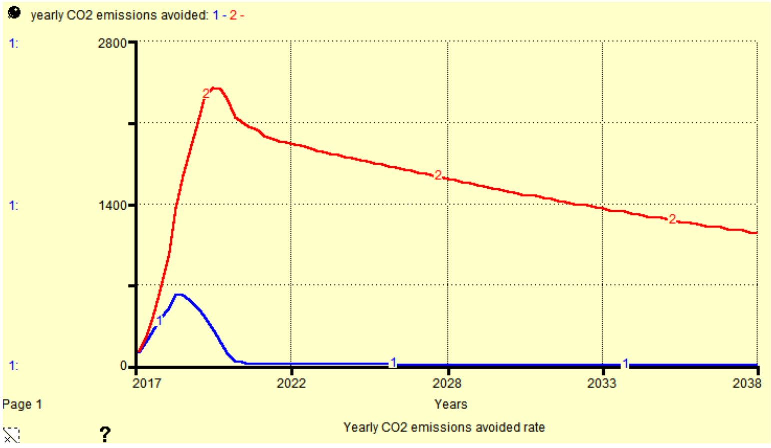

Figure 4.23. Behavior of "yearly CO_2 emissions avoided rate" with no policy (blue line) and first policy option (red line).

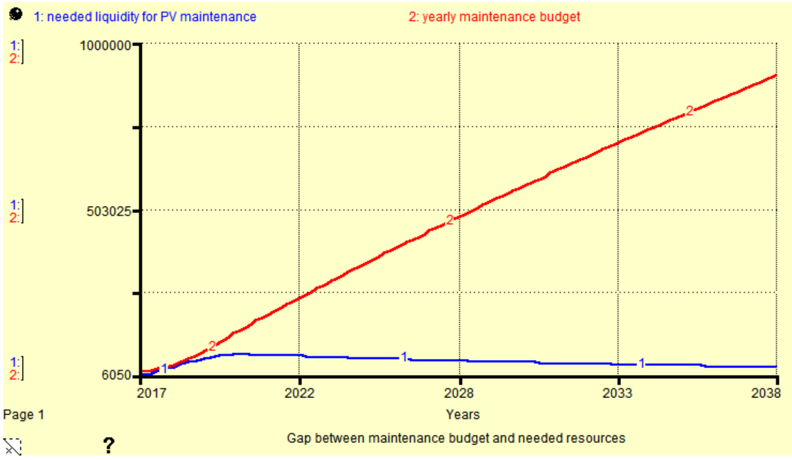

Figure 4.24. Gap between maintenance budget and needed resources under the first policy option.

Unlike the first basic scenario, the implementation of such a policy option allows achieving better simulation results, which can be briefly summarized as follows:

- the (full operational) installed PV capacity initially increases up to reach a peak of 377 kW *vs*. 198 kW (first scenario) and afterwards it starts slowly decreasing but it does not drop to zero as indeed happened under the first scenario (Figure 4.20). During the entire simulation length, such a stock gets higher values than the ones recorded in the first scenario thanks to the implementation of PV maintenance;
- indeed, unlike the first scenario, both the "*maintenance implementation rate*" and "*repairing rate*" are not equal to zero since now there are available resources for carrying out PV maintenance operations. That leads to a

reduction of their related stocks of "*PV capacity to be maintained*" and "*PV capacity broken*" (Figures 4.21; 4.22)[213];

- furthermore, one may take over that now the stock "*PV capacity broken to be maintained*" gets lower and lower values than the ones recorded under the first scenario (Figure 4.22) thanks also to the effect that "*maintenance implementation rate*" has – *ceteris paribus* – on the "*breakdown rate*"[214], which, in turn, is the inflow variable of the stock "*PV capacity broken to be maintained*";
- finally, lower stocks of "*PV capacity to be maintained*" and "*PV capacity broken*" allow a higher availability of (full operational) PV capacity that, in turn, leads to a greater "*green energy production rate*" and, thereby, higher quantity of "*CO_2 emissions avoided*" (almost four times more than the ones got under the first scenario; see Figure 4.23). That would translate into – *ceteris paribus* – a better environmental quality and, *lato sensu*, better quality of life.

Although the above simulation results are better than before, one may note that, from 2020 onwards, the installed PV capacity and consequently also the other (stock and flow) variables linked to it, start going down since, as already anticipated, PV investments take place just for a limited period (*i.e.* from 2017 to 2020)[215].

By running the S&F model with additional funds starting from 2020, the PV capacity would increase rather than decline. That would implicitly suggest the need for further financial resources – which could be also provided by the private sector – to ensure the installation of new PV plants on public buildings and hence the growth of PV capacity installed.

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[213] Note that under this policy option, "*PV capacity to be maintained*" reaches a peak of 693 kW *vs.* 1057 kW in the first scenario and afterwards it starts decreasing. Likewise, "*PV capacity broken*" stabilizes at 1 kW *vs.* 18 kW under the first scenario.

[214] Indeed, as already said, there is an indirect (negative) relationship between "maintenance implementation rate" and "breakdown rate". Thus, the higher the first one is, the lower the second one will be, and vice versa.

[215] Like the first basic scenario, this second scenario does not envisage further financial resources to be allocated to PV investments from 2020 onwards. Thus, the lack of further funds for new PVs alongside the depreciation of PV plants (depreciation rate) lead to a reduction of (full operational) PV capacity installed over the years.

Finally, there is another point to keep into consideration that concerns the liquidity ratio, which is higher than one for the entire simulation period. Indeed, the use of electricity bill savings for PV maintenance will generate further electricity bill savings as a result of the greater green energy production, which is positively affected by the implementation of PV maintenance[216].

If the electricity bill savings are higher than the resources needed for carrying out PV maintenance (Figure 4.24), then public decision-makers may decide to allocate the remaining gap for fulfilling other "needs"[217].

Although the first policy option allows achieving better patterns of behavior, there may still be other critical issues affecting the production of clean energy.

As already anticipated, the time for carrying out regular PV maintenance may be quite long (1 year or even more) due to bureaucratic red tape for issuing public tenders.

The internalization of PV maintenance operations – in place of the current outsourcing policy implying bureaucratic red tape – could make such operations faster and leaner though it might determine some changes in other areas belonging to the same organization such as, for instance, the human resource one.

A new model structure – briefly portrayed in Figure 4.25 – has been added to the previous one in order to test the internalization policy[218].

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[216] This process describes a reinforcing feedback loop.

[217] For instance, policy-makers may decide to allocate the new resources – generated from PV plants – for financing projects other than PV ones (*e.g.*, schools) thus contributing to improve the performance of other areas belonging to the Municipality of Palermo. Adopting a systemic view – in place of a tunnel vision – would allow key-actors to better understand the (direct or indirect) effects that a given decision or project promoted by an organizational area may have on other units or areas belonging to the same organization.

[218] Note that the model structure embodies the internalization policy just for the regular (preventive) PV maintenance since – after the implementation of the first policy option – the breakdown rate becomes very low. Therefore, in testing the second policy option, the focus is only on the regular (preventive) maintenance given the low "burden" of the corrective one.

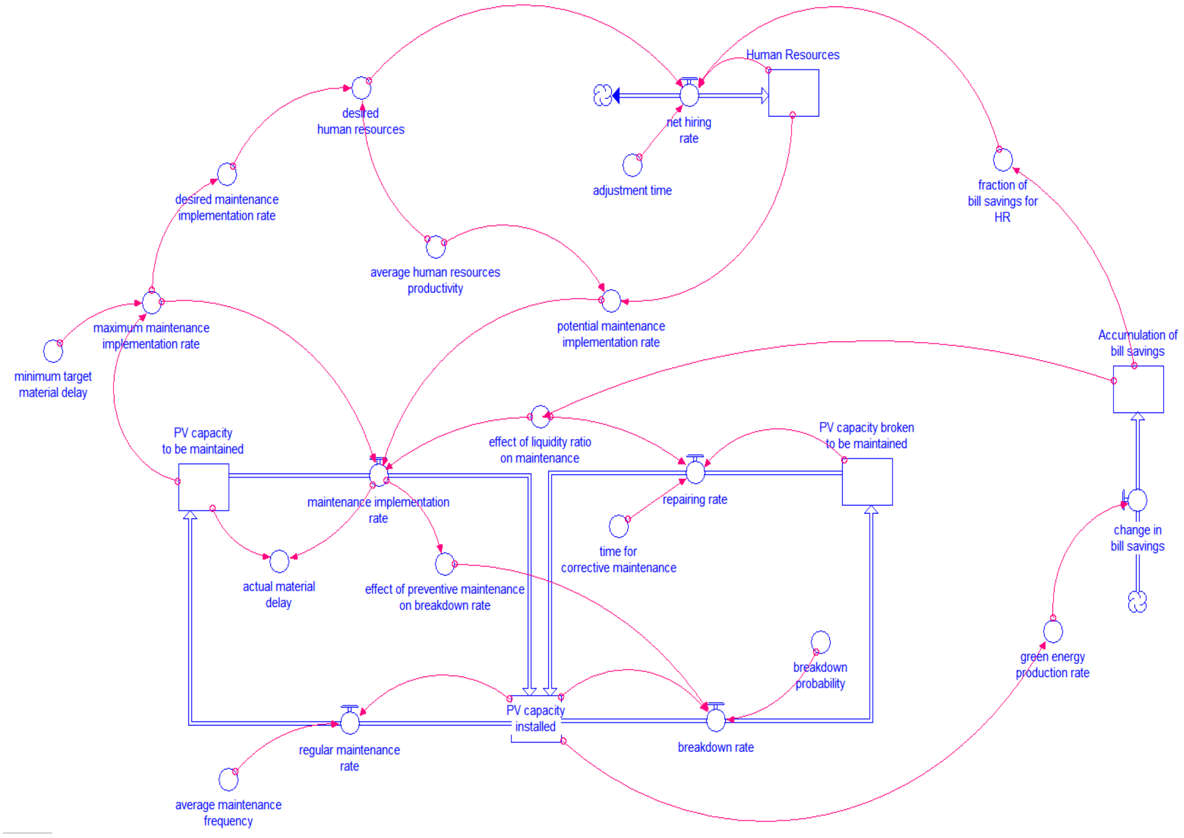

Figure 4.25. Stock & Flow structure for policy option 2 (simplified version).

The structure portrayed in Figure 4.25 envisages a set of conditions and dynamic hypotheses underlying the formulation of the second policy option[219] (corresponding to the third scenario), *i.e.*:

- the desired time for implementing regular PV maintenance (*alias* "*minimum target material delay*") is now set at 1 month[220], which is by far lower than the previous actual one (*i.e.* 1 year);
- the human resource structure is a first-order linear negative feedback system (Sterman, 2000) with an explicit goal *i.e.* the "*desired human resources*", which is not a fixed parameter but it is anchored to both the

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[219] Like the previous two scenarios, such a third case takes into account (NOP) funds for a limited period (*i.e.* from 2017 to 2020).

[220] Actually, the time for carrying out regular PV maintenance may be lower than 1 month but, here, the purpose is to understand what may happen in case of lower time required for PV maintenance regardless if it is set at 1 month or less than one month.

"*maximum maintenance implementation rate*"[221] and the "*average employee productivity*";

- PV maintenance operations would be still carried out through the partial use of electricity bill savings[222];
- the needed liquidity for eventually hiring new human resources would come from the remaining gap between the "*yearly electricity bill savings for PV maintenance*" and the amount does spent for PV maintenance (*i.e.* total maintenance costs).

By running the model structure under the above conditions and hypotheses, the following main patterns of behaviors have been obtained:

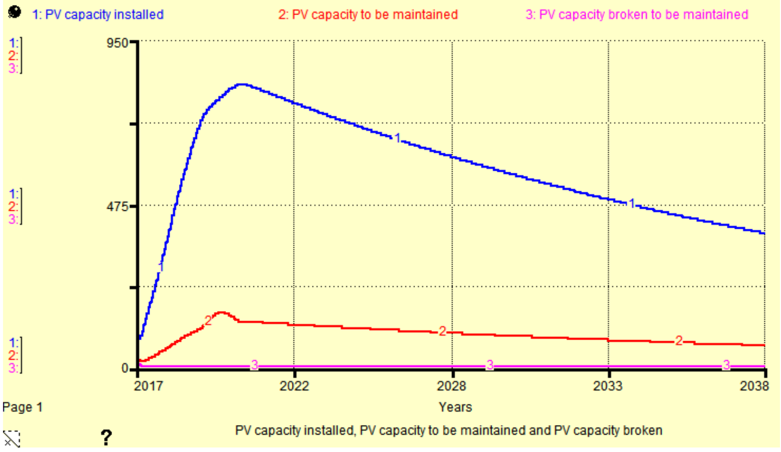

Figure 4.26. Behavior of (full operational) PV capacity installed, PV capacity to be maintained, and PV capacity broken (stock variables) with the second policy option (third scenario).

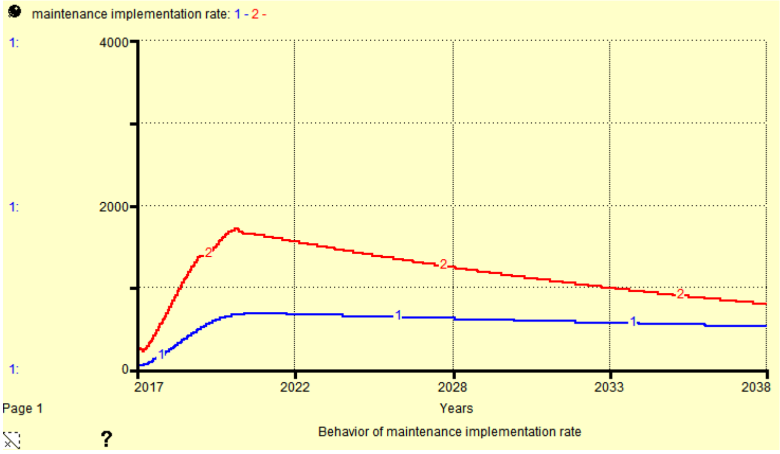

Figure 4.27. Behavior of "maintenance implementation rate" with first policy (first/blue line) and second policy option (second/red line).

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[221] Note that the "*maximum maintenance implementation rate*" is given by "PV capacity to be maintained/minimum target material delay".

[222] Like the previous second scenario, the fraction of electricity bill savings for PV maintenance is still equal to 40% of the total amount.

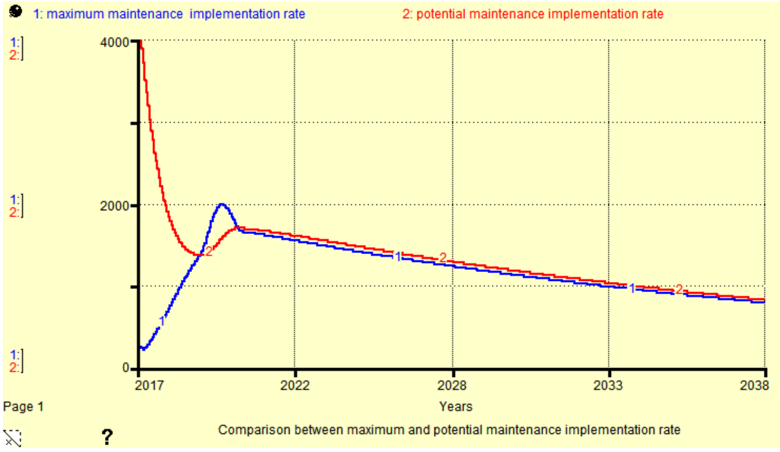

Figure 4.28. Comparison between maximum and potential maintenance implementation rate under the third scenario.

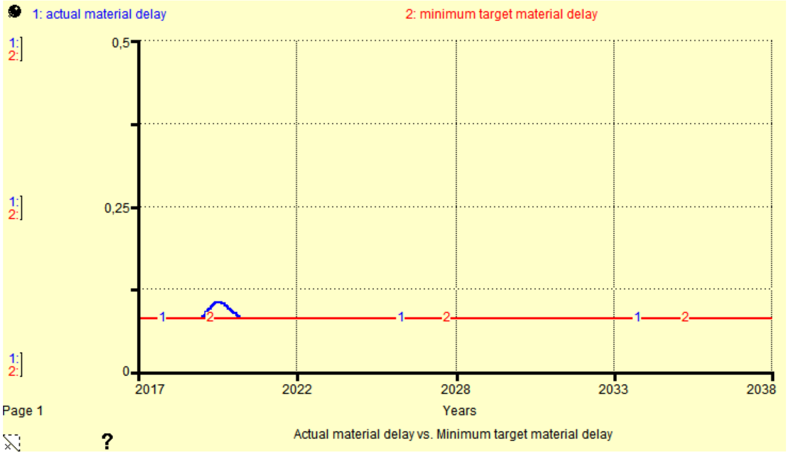

Figure 4.29. Comparison between actual and minimum material delay under the third scenario.

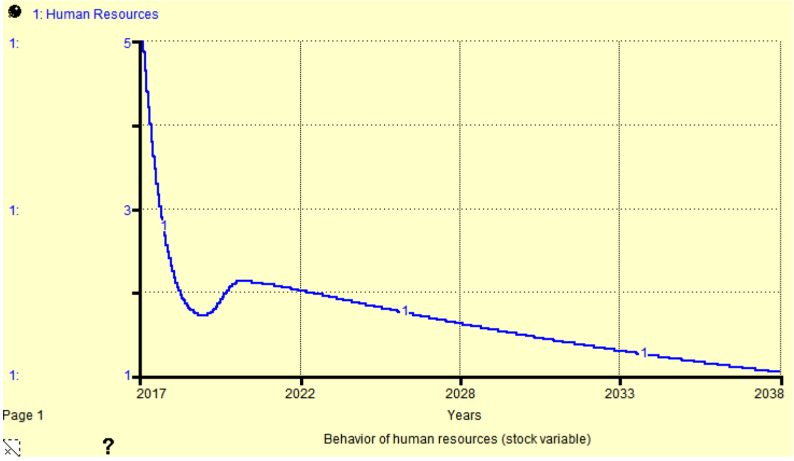

Figure 4.30. Behavior of human resources (stock variable) under the third scenario.

The main simulation results arising from the testing of the internalization policy for (regular) PV maintenance may be summarized as follows:

- the (full operational) installed PV capacity – during the entire simulation length – gets higher values than the ones recorded under both the first and second scenarios. Indeed, it starts increasing up to reach a peak of 825 kW in 2020 *vs*. 377 (second scenario) and afterwards it slowly goes down although it does not get value zero (Figure 4.26). As a result of such a policy, it is expected that Palermo Municipality may improve its financial, competitive, and social performance since higher (full operational) PV capacity leads to greater green energy production rate, electricity bill savings, CO_2 emissions avoided and then, *ceteris paribus*, better environmental quality;
- under this scenario, the higher (full operational) PV capacity does not only depend on the implementation of PV maintenance but also on the lower time needed for carrying out maintenance, now made possible thanks to the internalization policy. Therefore, cutting bureaucratic red tape allows increasing the "*maintenance implementation rate*" (Figure 4.27), given the yearly budget (threshold) for PV maintenance;
- notably, the flow variable "*maintenance implementation rate*" depends on two other variables *i.e*. "*maximum maintenance implementation rate*" and "*potential maintenance implementation rate*" (Figure 4.28; Figure 4.25). At first, "potential implementation rate" is higher than the "maximum implementation rate" since the available human resources – with their average productivity – are higher than the ones do needed for carrying out PV maintenance at the desired material delay equals to 1 month. That is why it is not surprising that the "human resource stock" goes down from 2017 to 2019 (Figure 4.30) in order to keep "potential implementation rate" equals to the maximum (desired) one. That happens in 2019 but soon after the "maximum implementation rate" – in correspondence to the peak of "PV capacity to be maintained" – becomes higher than the "potential

implementation rate" (Figure 4.26)[223]. That leads to a slight increase of the stock human resources from 2019 to 2020 in order to align the potential implementation rate with the maximum rate;

- finally, Figure 4.29 shows the behaviors of the "*actual material delay*" and the "*minimum target material delay*", which are equal to 0.08 year (~1 month) meaning that the flow "maintenance implementation rate" gets the "maximum maintenance implementation rate" during the entire simulation length. However, in 2019 there is an exception since the actual material delay is higher than the desired one. That happens right when the "maximum implementation rate" is higher than the "potential one" and therefore the flow "maintenance implementation rate" gets this latter value at least until new adjustments take place in order to keep the actual material delay equals to the minimum (desired) one.

The above simulation results would show how the internalization policy for PV maintenance – in place of the current outsourcing one – would lead to better patterns of behavior in terms of PV capacity installed, green energy production and, then, CO_2 emissions avoided.

A special remark is due for the behavior of the "human resources" stock (Figure 4.30). Indeed, its decreasing pattern does not necessarily imply the layoffs of the current employees as they may be asked to perform tasks other than the maintenance of PV systems.

Ultimately, by moving from the first scenario to third one, the situation improves thanks to the formulation of two policy options *i.e.* the use of electricity bill savings for carrying out PV maintenance and the internalization policy.

Indeed, as already discussed, the implementation of such policies may allow Palermo Municipality to increase its stock of "full operational PV capacity" and, then, the stock of "cumulative clean energy" (Figure 4.31).

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[223] Note that it takes time to keep "potential implementation rate" aligned to the "maximum implementation rate". Indeed, there is a delay that is due to the time needed for adjusting the stock "human resources".

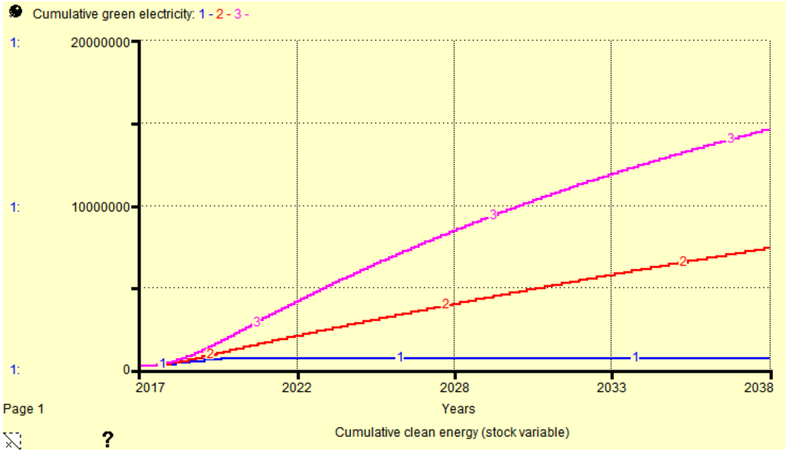

Figure 4.31. Behavior of "cumulative clean energy" stock variable under the first scenario (1), the second scenario (2), and the third scenario (3).

In particular, under the third scenario, the stock of "cumulative clean energy" reaches higher values than the ones recorded under the previous scenarios although, over a long-term horizon, it increases at a decreasing rate[224] (Figure 4.31). It is important to remark that this is not due to a "pathological" situation but rather it is strictly related to the lack of investments in new PV capacity from 2020 onwards. Indeed, as already said, all the three scenarios have been simulated by taking into account external financial resources allocated just for the period 2017-2020.

Therefore, in the future, there is the need to continue investing in PV systems in order to keep high the installed PV capacity that, in turn, is a necessary condition to generate more and more clean energy.

To this end, in the current context characterized by the lack of FIT schemes and the difficulties in applying for mortgages, Palermo Municipality is taking into account more innovative financing methods such as the involvement of ESCOs.

4.12. IMPLICATIONS.

In this section, a brief summary of the major implications drawn from research findings is presented.

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[224] Note that, under the third scenario, the inflow "green energy production rate" reaches higher values than the ones got under the previous scenarios. However, in the long-term horizon, it starts slowly decreasing.

The findings emerging from the case study analysis can provide public decision-makers useful insights on the role the suggested DPM approach can play to enhance the formulation and evaluation of policies for PVs in a local government.

The model developed for Palermo Municipality provides a means of allowing decision-makers to better understand how they may improve the performance of the PV sector with a view to achieving a sustainable development in the long-time horizon in terms of clean energy production.

Indeed, the design and implementation of a DPM approach provide an opportunity for decision-makers to assess the short- and medium/long- term effects of alternative policies and to adopt a cause and effect perspective when dealing with complex issues.

By having the support of such an approach, decision-makers are able to identify and manage those strategic resources and performance drivers that have an effect on the end-results and, then, on the PV sector's performance. Thus, they can select the most suitable policy levers through which they can influence a system's performance to attain the desired results (outcomes).

The insights emerging from this case study also reveal how the design and application of a DPM approach can add value to the traditional PM systems. It has emerged how the combination of SD modeling with the traditional planning and control systems may represent a good approach to foster the adoption of a learning-oriented perspective, which is crucial to avoid a static, non-systemic and mechanistic approach to planning and control processes of public sector organizations. In this sense, the findings from the case study analysis contribute to the body of knowledge concerning the usefulness of a DPM as a method to enhance policy design and evaluation for PVs in the public sector.

Finally, although the model has been built for the Municipality of Palermo[225], it can provide a basis that may be taken into account, *mutatis mutandis,* by other local governments engaged to limit CO_2 emissions by means of technologies based on RES_s.

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[225] Although the developed model supports the objective, it can be enriched to take into account other factors and features to be included into the model. Numerous extensions can be proposed. For more detail, see Section "Limitations and recommendations for future research".

4.13. CLOSING REMARKS.

In this Chapter, the focus has been on the PV sector of Palermo Municipality, which has recorded a decreasing trend over the last years (Figure 4.6).

Based on such a trend, an analysis of the main critical issues – affecting the adoption of PV systems in the Municipality of Palermo – has been carried out.

In particular, such an analysis has revealed, *inter alia*, problems concerning PV maintenance operations mainly due to two factors *i.e.* the lack or shortage of financial resources on the one hand and the "burden" of bureaucratic red tape on the other.

Both of these factors, together with the other critical issues already presented (Figure 4.1), may adversely affect the production of clean energy and, then, the achievement of a sustainable development in the long term.

Based on this, the design and application of a DPM approach – tailored to Palermo Municipality with reference to the PV sector – followed.

Main insights emerging from this case study have shown how the combination of SD modeling with the traditional PM systems *i.e.* DPM approach may support public decision-makers in:

- better understanding how strategic resources may affect performance drivers that, in turn, affect end-results as well as how these latter may influence strategic-asset accumulation and depletion processes (*i.e.* instrumental view of performance). For instance, as already shown in the DPM chart, the stock "liquidity" affects the performance driver "liquidity ratio" that, in turn, influences the "change in maintenance implementation/repairing rate". Finally, this latter influences the stock of "full operational PV capacity";
- identifying major feedback loops underlying performance (Figure 4.11);
- designing and testing policies aimed at fostering the achievement of a sustainable development in terms of clean energy. Indeed, by moving from the first basic scenario to the third one, better results have been achieved in terms of PV capacity installed, clean energy production and, then, CO_2 emissions avoided;

- assessing policy impacts/effects in both the short- and long-term horizons thus allowing one to understand counterintuitive behaviors. For instance, under the first scenario, the installed PV capacity increased at first. However, in the medium/long-term horizon, it went down due to the side effects associated with the lack of PV maintenance (Figure 4.16);
- measuring performance not only within the financial dimension but also under the social and competitive ones. Indeed, in designing and applying a DPM approach, a set of performance drivers were identified by taking into account all the three dimensions (*e.g.*, liquidity ratio, CO_2 emission ratio, and image ratio);
- raising public decision-makers' awareness of the advantages associated with the adoption of renewable energy sources.

Ultimately, the design and application of a DPM approach may enhance traditional PM systems by overcoming their limitations. As such, it may improve public decision-makers' strategic learning processes with a view to outlining sustainable policies in the long run.

CONCLUSIONS

The overall purpose of this research study has been to provide a contribution to the field of the PV sector with reference to the formulation of public policies for sustainable development in terms of clean energy.

The need to support public decision-makers in outlining sustainable policies for PVs mainly arises from two reasons.

Firstly, today, there is a compelling need to reduce CO_2 emissions and, then, to address global warming.

Italian public organizations (primarily the local ones) are expected to take an active role in order to provide their contribution in reducing CO_2 emissions through, for instance, the adoption of solar PV systems.

Secondly, over the last few years, the growth of PV capacity installed in the Italian public sector has slowed down and this is likely due to some recent changes (*e.g.*, the end of FIT schemes).

Based on this, after an introduction of the main features of solar PV technology, one has attempted to understand how the traditional PM systems may contribute in supporting PV investments, installation, and usage in the public sector.

Although such PM systems represent useful frameworks for designing strategies and measuring results, they would not be able to deal with the dynamic complexity that characterizes the systems in which public decision-makers operate.

This is mainly due to their limitations such as, for instance, a narrow focus on the financial performance, on the short-term horizon and on the institutional perspective, a lack of linkage between outputs and outcomes, and a misperception (or even lack of detection) of delays and feedback loops.

As such, dysfunctional behaviors – generated by a loose application of PM systems (*e.g.*, myopia, and tunnel vision) – may lead to poor, biased strategic decisions concerning the adoption of PV systems in the public sector.

In order to overcome the above shortcomings, SD methodology has been combined with the traditional PM systems, *i.e*. DPM approach.

From a theoretical viewpoint, it has emerged that a DPM approach may contribute in improving public policy design for PVs thanks to the support of the SD in enhancing public decision-makers' strategic learning processes.

In particular, a DPM approach allows decision-makers to take into account the institutional and inter-institutional perspectives and, then, the outcomes associated with the implementation of public policies.

For instance, public decision-makers may better understand to what extent their PV investment policies contribute to generate value for the wider system in which they operate, *e.g*. in terms of environmental quality, local area image, and community's life quality (outcomes).

Moreover, a DPM approach may contribute to frame potential trade-offs in time. For instance, it may support decision-makers in capturing the main short- and long-term effects associated with a decision to not adopt PV systems as part of an indiscriminate discretionary costs cutting policy.

In order to test the effectiveness of such an approach through empirical evidences, an application to the PV sector of the Municipality of Palermo has been provided.

The starting point has been represented by the decreasing trend in PVs that Palermo Municipality has recorded over the last years. Based on this, an analysis of the main critical issues – affecting the adoption of PV systems – has been carried out at first.

Such an analysis has revealed a number of factors that still today affect the PV sector of Palermo Municipality such as, for instance, bureaucratic red tape which in most cases are responsible for delays in PV maintenance operations as well as the shortage of financial resources for both PV installation and maintenance.

Moreover, other critical issues are associated with dysfunctional behaviors (*e.g*., myopia, tunnel, and departmental view) that, in turn, may arise as a result of a loose application of effective strategic management mechanisms.

In order to deal with the above critical issues, a DPM framework has been designed and implemented by adopting an "instrumental view" of performance and an “inter-departmental” perspective in order to identify the main strategic resources, performance drivers and end-results on the one hand and the main interconnections between the involved organizational units on the other.

The resulting DPM framework and the CLD have provided the basis for building a S&F foresight model to perform scenario analysis through computer simulations.

In particular, two policies for PVs have been formulated and tested. The simulation results have shown how Palermo Municipality, through the implementation of such policies, may improve its PV sector performance in terms of PV capacity installed and, then, clean energy production.

Ultimately, the empirical evidences emerging from such a case study reveal how the design and application of a DPM approach to the PV sector may effectively improve the strategic learning processes of Palermo Municipality’s decision-makers with a view to achieving a sustainable development in the long run.

LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This research study presents some limitations that are mainly associated with the adoption of the SD methodology although, as already stated, it can contribute to enhance the traditional PM systems.

The first limitation has much to do with Sterman's statement according to which "*all models are wrong*" (Sterman, 2002), meaning that all models are limited, simplified representations of the real world.

Indeed, the model built for the PV sector of Palermo Municipality is simplified compared to the complexity of the system in which its public decision-makers operate.

The model encompasses the main causal effect relationships, nonlinearities, and variables considered the most relevant ones in relation to the purpose of this research study. For such a reason, some relationships or variables have not been included under the domain of analysis.

For instance, the model does not represent the dynamics of the PV technology price in relation to the potential developments of the PV industry. In addition, the model does not take into account the effects of CO_2 emission reductions on community's life quality as well as the effects of the adoption of PV systems on green job market.

Moreover, it is important to remark that the developed model has not a predictive power. Indeed, it has been built to improve public decision-makers' mental models by testing, in a "virtual world", alternative policies rather than to "predict" what will happen in the future.

Furthermore, during the quantitative modeling phase, a problem of data gap has emerged with reference to some variables (*e.g.*, "average employee productivity for PV maintenance"). Such a difficulty has been overcome by formulating hypotheses and assumptions based on data gathered during the interviews.

Here, it is worth to point out that the aim of the model is not to identify the "precise values" of the variables but rather to portray their patterns of behavior over time by making use of accurate information as well as hypotheses whenever numerical data is not available.

Based on the above limitations, further research will be necessary to develop more knowledge on the application of a DPM approach to the PV sector in public organizations, especially for what concerns the linkages between the institutional and the inter-institutional levels of analysis.

In addition, since public sector is a complex system characterized by multiple (both private and public) actors involved, a DPM approach may be designed and implemented to further collaboration and synergies between *e.g.* the private and public sector with a view to fostering the achievement of a sustainable energy development in the long run.

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DIRECTIVE 2006/32/EC	*Energy end-use efficiency and energy services*
DIRECTIVE 2009/28/EC	*Promotion of the use of energy from renewable sources*
DIRECTIVE 2010/31/EU	*Energy performance of buildings*
DIRECTIVE 2012/27/EU	*Energy efficiency*

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LAW no. 10/91	*Regulations for implementing the Energy National Plan, with matters relating to national energy use, energy saving, and renewable energy sources*
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Ministerial Decree of 6 August 2010	*Third feed-in tariff scheme*
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APPENDIX A: MODEL EQUATIONS

Stock variables:

- Accumulation of electricity bill savings(t) = Accumulation of electricity bill savings(t - dt) + (change in accumulation of electricity savings) * dt
- CO_2 emissions avoided(t) = CO_2 emissions avoided(t – dt) + (change in CO_2 emissions) * dt
- Cumulative CO_2 emissions avoided(t) = Cumulative CO_2 emissions avoided (t – dt) + (yearly CO_2 emissions avoided) * dt
- Cumulative green electricity(t) = Cumulative green electricity(t – dt) + (green energy production rate – green energy selling rate) * dt
- Environmental quality(t) = Environmental quality(t – dt) + (change in environmental quality) * dt
- Human resources(t) = Human resources(t –dt) + (net hiring rate) * dt {*third scenario*}
- INIT Accumulation of electricity bill savings = Cumulative green electricity*avg ENEL electricity price
- INIT CO_2 emissions avoided = maximum CO_2 emissions avoidable*energy ratio
- INIT Cumulative CO_2 emissions avoided = 54096
- INIT Cumulative green electricity = 112000
- INIT Environmental quality = Initial value environmental quality
- INIT Human resources = 5 {*third scenario*}
- INIT Liquidity for HR = 0 {*third scenario*}
- INIT Liquidity for PV investments =0
- INIT Liquidity for PV maintenance = 0
- INIT Palermo Municipality Image = Initial Palermo Municipality’s image
- INIT PV capacity broken to be maintained = 5
- INIT PV capacity installed = 80
- INIT PV capacity to be maintained = 20
- INIT PV unit price = 2000

- INIT Total cost PV installed = 160000
- INIT total employees = 2
- Liquidity for HR(t) = Liquidity for HR(t – dt) + (change in liquidity for HR) * dt {*third scenario*}
- Liquidity for PV investments(t) = Liquidity for PV investments(t – dt) + (cash inflow – cash outflow) * dt
- Liquidity for PV maintenance(t) = Liquidity for PV maintenance(t – dt) + (cash in – cash out) * dt
- Palermo Municipality Image(t) = Palermo Municipality Image(t – dt) + (change in image) * dt
- PV capacity broken to be maintained(t) = PV capacity broken to be maintained(t – dt) + (breakdown rate – repairing rate) * dt
- PV capacity installed(t) = PV capacity installed(t – dt) + (capacity installation rate + repairing rate + maintenance implementation rate – capacity depreciation rate – regular maintenance rate – breakdown rate) * dt
- PV capacity to be maintained(t) = PV capacity to be maintained(t – dt) + (regular maintenance rate – maintenance implementation rate) * dt
- PV unit price(t) = PV unit price(t – dt) + (change in PV unit price) * dt
- Total cost PV installed(t) = Total cost PV installed(t – dt) + (cost installation rate – cost depreciation rate) * dt
- Total employees(t) = Total employees(t – dt)

Inflows:

- Breakdown rate = PV capacity installed*probability to breakdown*effect of implementation ratio on breakdown rate
- Capacity installation rate = normal capacity installation rate*effect of PV project time ratio on capacity installation rate
- Cash in = yearly internal funds for PV maintenance+yearly external funds for PV maintenance+bill savings for PV maintenance
- Cash inflow = if(avg private funds attractiveness=1 or avg private funds attractiveness>1) then(EU funds for PVs+(additional private funds*avg private funds attractiveness)) else(EU funds for PVs)

- Change in accumulation of electricity savings = green energy production rate*avg Enel electricity price
- Change in CO_2 emissions = ((maximum CO_2 emissions avoidable*Energy ratio)-CO_2 emissions avoided)/adjustment time
- Change in environmental quality = ((Environmental quality*effect of CO_2 emission ratio on environmental quality)-Environmental quality)/time to affect environmental quality
- Change in image = ((effect of environmental quality on image*Palermo Municipality Image)-Palermo Municipality Image)/image adjustment time
- Change in liquidity for HR = max(0, remaining funds for HR) {*third scenario*}
- Change in PV unit price = (Indicated PV unit price-PV unit price)/adjustment time
- Cost installation rate = yearly budget for PVs
- Green energy production rate = maximum production rate*operational capacity ratio*module efficiency
- Maintenance implementation rate = if(liquidity ratio=1 or liquidity ratio>1) then(normal implementation rate) else(min(normal implementation rate, real regular maintenance) {*first & second scenario*}
- Maintenance implementation rate = if(liquidity ratio=1 or liquidity ratio>1) then (effective maintenance implementation rate) else(min(effective maintenance implementation rate, real regular maintenance) {*third scenario*}
- Net hiring rate = (human resources needed-human resources)/adjustment time HR {*third scenario*}
- Regular maintenance rate = PV capacity installed/avg maintenance frequency
- Repairing rate = if(liquidity ratio=1 or liquidity ratio>1) then(PV capacity broken to be maintained/time to implement corrective maintenance) else(min(PV capacity broken to be maintained/time to implement corrective maintenance, real corrective maintenance)

- Yearly CO_2 emissions avoided = maximum CO_2 emissions avoidable*Energy ratio

Outflows:

- Breakdown rate = PV capacity installed*probability to breakdown*effect of implementation ratio on breakdown rate
- Capacity depreciation rate = cost depreciation rate*avg PV installed capacity
- Cash out = total maintenance cost
- Cash outflow = cost installation rate
- Cost depreciation rate = Total cost PV installed*depreciation rate
- Green electricity selling rate = Cumulative green electricity*percentage of electricity sold
- Maintenance implementation rate = if(liquidity ratio=1 or liquidity ratio>1) then(normal implementation rate) else(min(normal implementation rate, real regular maintenance)) {*first & second scenario*}
- Maintenance implementation rate = if(liquidity ratio=1 or liquidity ratio>1) then (effective maintenance implementation rate) else(min(effective maintenance implementation rate, real regular maintenance) {*third scenario*}
- Regular maintenance rate = PV installed capacity/avg maintenance frequency
- Repairing rate = if(liquidity ratio=1 or liquidity ratio>1) then(PV capacity broken to be maintained/time to implement corrective maintenance) else(min(PV capacity broken to be maintained/time to implement corrective maintenance, real corrective maintenance)

○ *Auxiliary variables*:

- Actual completion time projects = 1/completion rate projects
- Actual material delay = PV capacity to be maintained/maintenance implementation rate {*third scenario*}
- Additional private funds = 100000
- Adjustment time = 1

- Adjustment time HR = 1 {*third scenario*}
- Avg corrective maintenance cost = 250
- Avg electricity production = 1400
- Avg employees productivity = 1
- Avg Enel electricity price = 0.3
- Avg HR productivity for maintenance = 800 {*third scenario*}
- Avg maintenance frequency = 0.5
- Avg personnel cost = 12000 {*third scenario*}
- Avg private funds attractiveness = normal private funds attractiveness+effect of image ratio on private funds attractiveness
- Avg PV installed capacity = PV installed capacity/Total cost PV installed
- Avg regular maintenance cost = needed liquidity for regular maintenance/regular maintenance rate
- Avg yearly energy consumptions from fossil fuels = 40000000
- Bill savings for PV maintenance = accumulation of electricity bill savings*fraction of bill savings for maintenance
- CO_2 emission factor = 0.483
- CO_2 emission ratio = CO_2 emission avoided/targetCO_2 emission reduction
- Competitiveness & employment rate = 0.354
- Competitors’ image = 0.8
- Completion rate projects = Total employees*employees’ productivity
- Conduction losses = 0.01
- Cost fraction for regular maintenance = 0.03
- Depreciation rate = 0.05
- Desired completion rate projects = 4
- Desired completion time projects = 1/desired completion rate projects
- Desired human resources for maintenance = desired maintenance implementation rate/avg HR productivity for maintenance {*third scenario*}
- Desired maintenance implementation rate = max(0, maximum maintenance implementation rate) {*third scenario*}
- Desired PV unit price = 1000
- Economic development = (tourism+ competitiveness & employment rate)/2

- Effect of age on probability to breakdown = GRAPH(PV age ratio) (0.00, 0.9), (0.5, 0.938), (1.00, 1.00), (1.50, 1.07), (2.00, 1.10)
- Effect of CO_2 emission ratio on environmental quality=GRAPH(CO_2 emission ratio) (0.00, 1.00), (0.08, 1.01), (0.16, 1.01), (0.24, 1.01), (0.32, 1.02), (0.4, 1.02), (0.48, 1.02), (0.56, 1.02), (0.64, 1.02), (0.72, 1.03), (0.8, 1.04), (0.88, 1.05), (0.96, 1.06), (1.04, 1.08), (1.12, 1.11), (1.20, 1.13), (1.28, 1.15), (1.36, 1.17), (1.44, 1.19), (1.52, 1.20), (1.60, 1.22), (1.68, 1.24), (1.76, 1.26), (1.84, 1.27), (1.92, 1.29), (2.00, 1.29)
- Effect of environmental quality on image=GRAPH(Environmental quality) (0.00, 1.00), (0.0909, 1.01), (0.182, 1.02), (0.273, 1.02), (0.364, 1.03), (0.455, 1.04), (0.545, 1.05), (0.636, 1.06), (0.727, 1.07), (0.818, 1.09), (0.909, 1.11), (1.00, 1.12), (1.09, 1.13), (1.18, 1.15), (1.27, 1.16), (1.36, 1.18), (1.45, 1.20), (1.55, 1.22), (1.64, 1.25), (1.73, 1.28), (1.82, 1.28), (1.91, 1.29), (2.00, 1.30)
- Effect of image ratio on private funds attractiveness=GRAPH(Image ratio) (0.00, 0.9), (0.5, 0.911), (1.00, 1.00), (1.50, 1.04), (2.00, 1.10)
- Effect of implementation ratio on breakdown rate=GRAPH(maintenance implementation ratio) (0.00, 1.10), (0.25, 0.971), (0.5, 0.585), (0.75, 0.396), (1.00, 0.3)
- Effect of implementation ratio on module efficiency=GRAPH(maintenance implementation ratio) (0.00, 0.95), (0.5, 0.974), (1.00, 1.00), (1.50, 1.04), (2.00, 1.10)
- Effect of PV capacity ratio on employees' productivity=GRAPH(PV capacity ratio) (0.00, 0.9), (0.5, 0.936), (1.00, 1.00), (1.50, 1.07), (2.00, 1.10)
- Effect of PV capacity ratio on indicated PV unit price=GRAPH(PV capacity ratio) (0.00, 1.00), (0.5, 1.00), (1.00, 1.00), (1.50, 0.926), (2.00, 0.9)
- Effect of PV price ratio on normal capacity installation rate=GRAPH(PV unit price ratio) (0.00, 0.95), (0.5, 0.962), (1.00, 1.00), (1.50, 1.03), (2.00, 1.10)
- Effect of PV project time ratio on capacity installation rate=GRAPH(PV project time ratio) (0.00, 1.00), (0.5, 1.00), (1.00, 1.00), (1.50, 0.989), (2.00, 0.98)

- Effective maintenance implementation rate = min(maximum maintenance implementation rate, potential maintenance implementation rate) {*third scenario*}
- Employees’ productivity = average employees productivity*effect of PV capacity ratio on employees’ productivity
- Energy ratio = green energy production rate/(green energy production rate+avg yearly energy consumptions from fossil fuels)
- EU funds for PVs = GRAPH(time) (2017, 700000), (2018, 995654), (2019, 700000), (2020, 100000), (2021, 0.00), (2022, 0.00), (2023, 0.00), (2024, 0.00), (2025, 0.00), (2026, 0.00), (2027, 0.00), (2028, 0.00), (2029, 0.00), (2030, 0.00), (2031, 0.00), (2032, 0.00), (2033, 0.00), (2034, 0.00), (2035, 0.00), (2036, 0.00), (2037, 0.00), (2038, 0.00)
- Fraction of bill savings for maintenance = 0.4
- Full operational capacity = PV capacity installed
- Gap = yearly maintenance budget – needed liquidity for PV maintenance
- Human resources needed = min(maximum number of HR, desired human resources for maintenance) {*third scenario*}
- Image adjustment time = 1
- Image ratio = Palermo Municipality Image/Competitors’ image
- Indicated PV unit price = PV unit price*effect of PV capacity ratio on indicated PV unit price
- Initial Palermo Municipality’s image = (life quality+economic development+initial value environmental quality)/3
- Initial value environmental quality = (particulate matter in the air+RESs production)/2
- Life quality = (public green+waste recycling+public transportation)/3
- Liquidity ratio = yearly maintenance budget/needed liquidity for PV maintenance
- Losses for high temperatures = 0.07
- Losses from inverter problems = 0.05
- Losses from solar radiation = 0.02

- Maintenance implementation ratio = maintenance implementation rate/normal implementation rate {*first & second scenario*}
- Maintenance implementation ratio = maintenance implementation rate/effective maintenance implementation rate {*third scenario*}
- Material delay ratio = actual material delay/minimum target material delay {*third scenario*}
- Maximum CO_2 emissions avoidable = CO_2 emission factors*green energy production rate
- Maximum maintenance implementation rate = PV capacity to be maintained/minimum target material delay {*third scenario*}
- Maximum number of HR = change in liquidity for HR/average personnel cost {*third scenario*}
- Maximum production rate = total capacity installed*avg electricity production
- Minimum target material delay = 0.08 {*third scenario*}
- Module efficiency = (standard module efficiency-potential losses from PVs)*effect of implementation ratio on module efficiency
- Needed liquidity for corrective maintenance = (PV capacity broken to be maintained*avg corrective maintenance cost)/year
- Needed liquidity for PV maintenance = needed liquidity for regular maintenance+needed liquidity for corrective maintenance
- Needed liquidity for regular maintenance = total cost PV installed*cost fraction for regular maintenance
- Normal capacity installation rate = (cost installation rate/(PV unit price*effect of PV price ratio on normal capacity installation rate))
- Normal implementation rate = PV capacity to be maintained/normal time to implement regular maintenance
- Normal private funds attractiveness = 0
- Normal probability to breakdown = 0.02
- Normal time to implement regular maintenance = 1
- Operational capacity ratio = full operational capacity/total capacity installed
- Particulate matter in the air = 0.5714

- Percentage of electricity sold = 0
- Potential losses from PVs = losses for high temperatures+losses from solar radiation+conduction losses+losses from inverter problems
- Potential maintenance implementation rate = avg HR productivity for maintenance*Human Resources {*third scenario*}
- Price adjustment time = 1
- Probability to breakdown = normal probability to breakdown*effect of age on probability to breakdown
- Public green = 0.011
- Public transportation = 0.235
- PV age ratio = PV average lifetime/reference lifetime
- PV average lifetime = PV capacity installed/capacity depreciation rate
- PV capacity ratio = PV capacity installed/target PV capacity
- PV project time ratio = actual completion time projects/desired completion time projects
- PV unit price ratio = PV unit price/desired PV unit price
- Real corrective maintenance = max(0,((yearly maintenance budget-needed liquidity for regular maintenance)/avg corrective maintenance cost))
- Real regular maintenance = yearly maintenance budget/avg regular maintenance cost
- Reference lifetime = 15
- Remaining funds for HR = bill savings for PV maintenance-total maintenance cost {*third scenario*}
- RESs production = 0.1324
- Standard module efficiency = 1
- Target CO_2 emission reductions = 690000
- Target PV capacity = 1000
- Time to affect environmental quality = 1
- Time to implement corrective maintenance = 0.33
- Total capacity installed = full operational capacity+PVcapacity to be maintained+PV capacity broken to be maintained

- Total corrective maintenance cost = repairing rate*avg corrective maintenance cost
- Total expenses = cost depreciation rate+total regular maintenance cost+total corrective maintenance cost
- Total maintenance cost = total regular maintenance cost+total corrective maintenance cost
- Total regular maintenance cost = maintenance implementation rate*avg regular maintenance cost
- Tourism = 0.083
- Waste recycling = 0.089
- Year = 1
- Yearly budget for PVs= cash inflow
- Yearly external funds for PV maintenance = 0
- Yearly internal funds for PV maintenance = 0
- Yearly maintenance budget = cash in

APPENDIX B: MODEL STRUCTURE

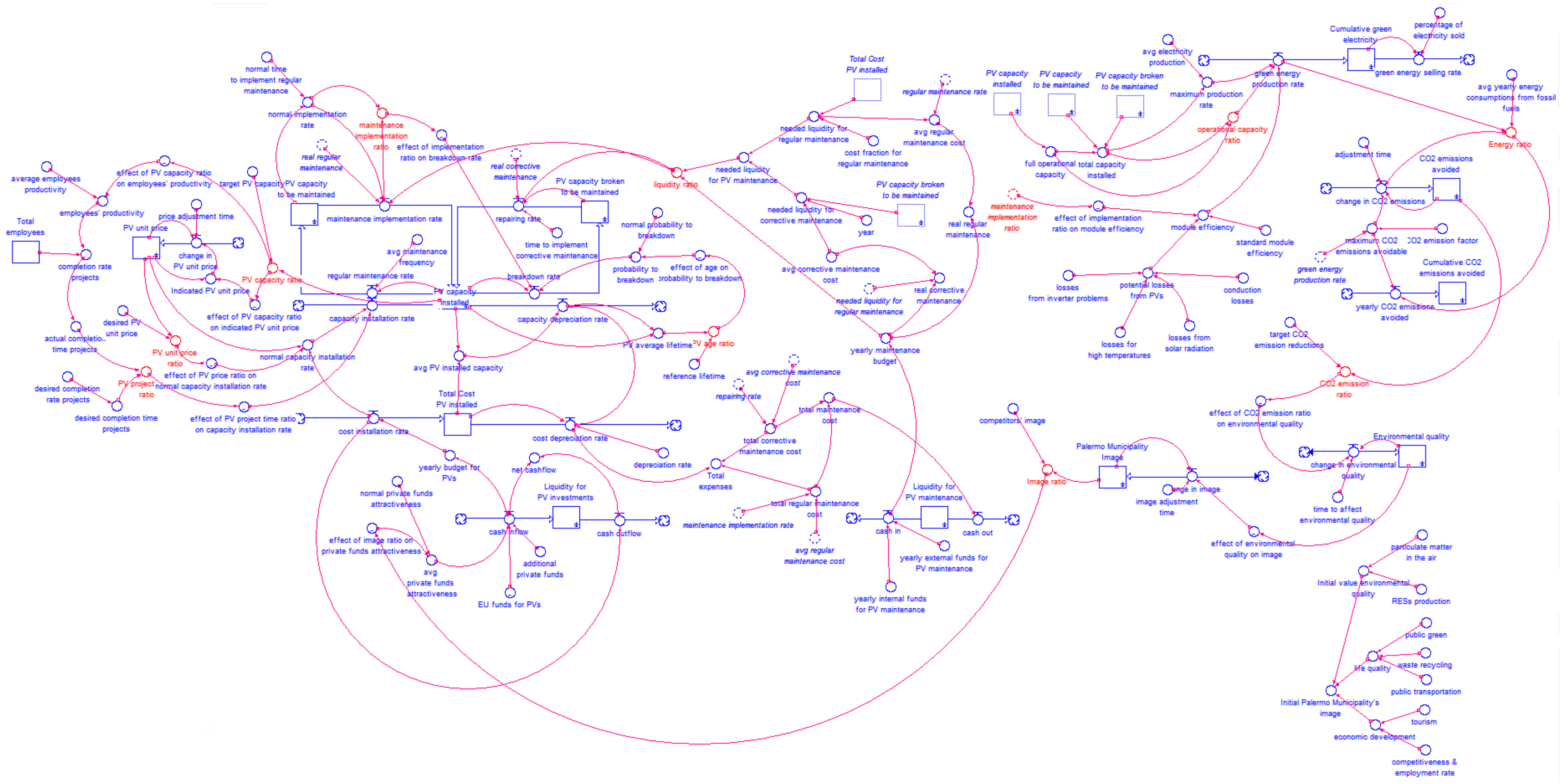

Figure 1. Model structure with no policy.

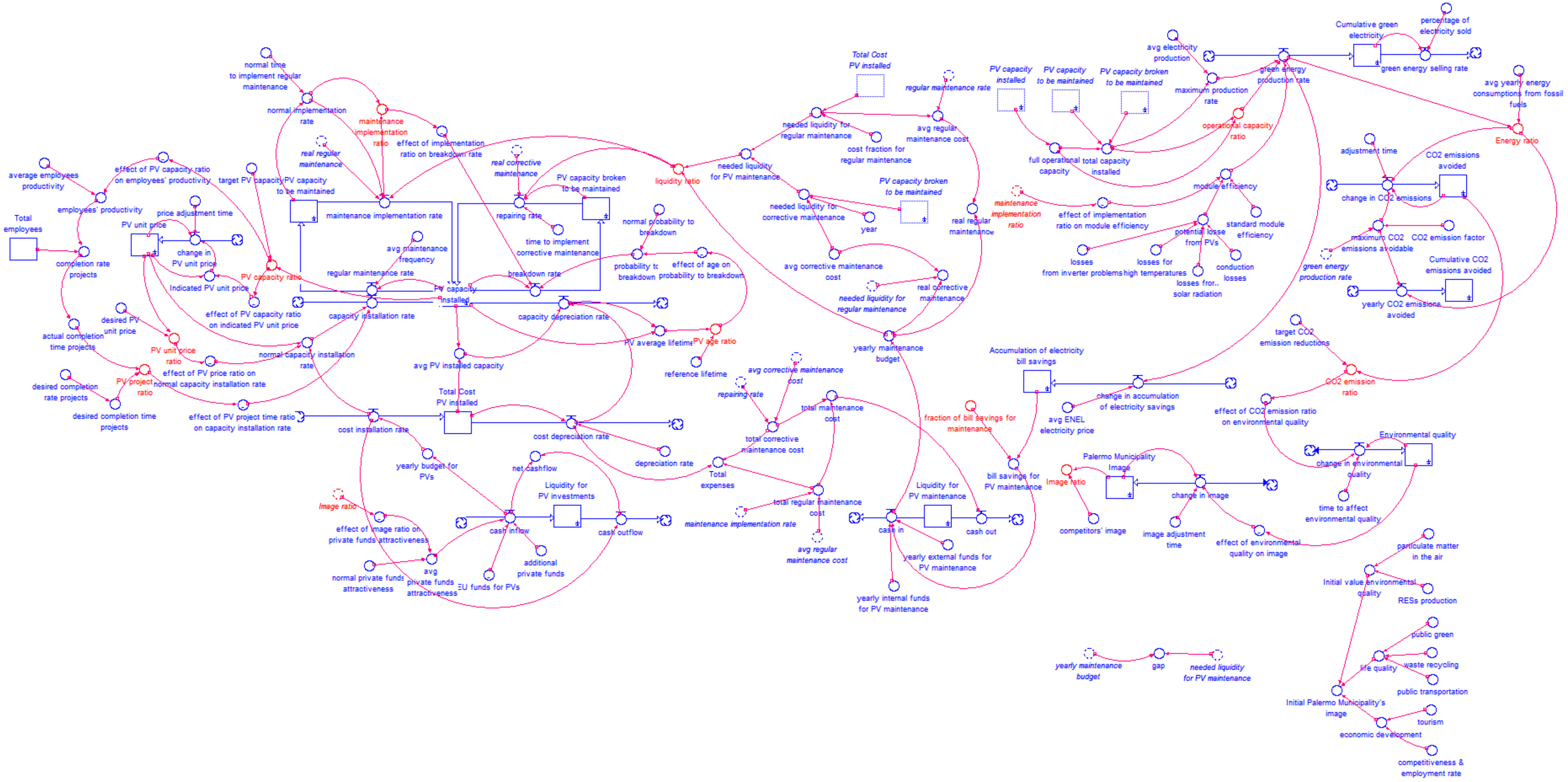

Figure 2. Model structure with first policy implemented.

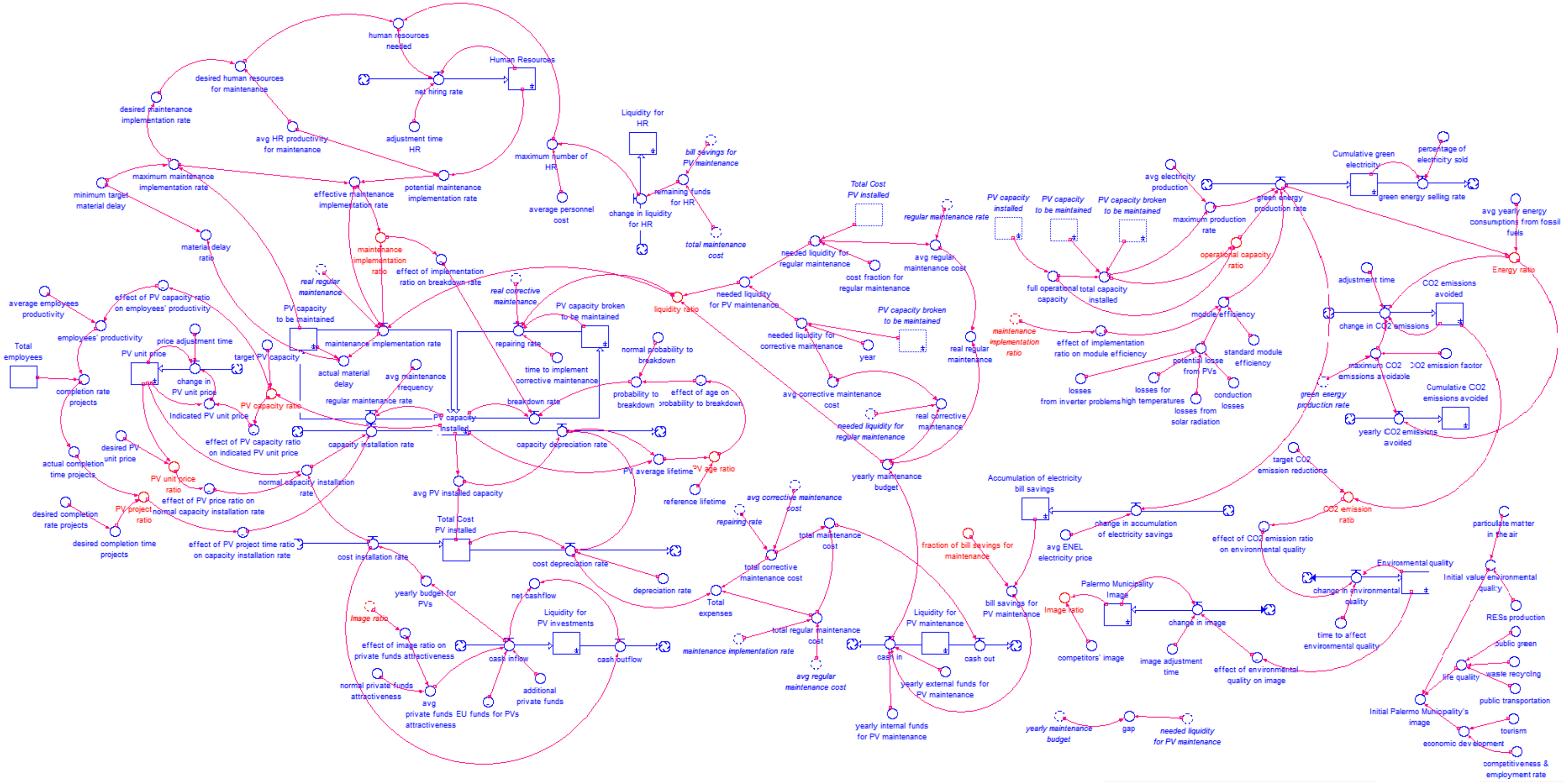

Figure 3. Model structure with second policy implemented.