The incoming global technological and industrial revolution towards competitive sustainable manufacturing

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ARTICLE INFO

Keywords: Sustainable development Manufacturing Manufacture

ABSTRACT

The major global challenges we are facing today need to be addressed in the multifaceted context of economy, society, environment and technology (ESET). In recent years, the consensus of calling for sustainable development (SD) and implementation has emerged. Along with this belief, high added value, knowledge-based, competitive sustainable manufacturing (CSM) has been widely considered as main enabler. This paper presents the necessary steps from economic growth to sustainable development. The reference model for proactive action (RMfPA) is proposed to develop and implement CSM, at national and global levels. Furthermore, we also review strategies to pursue CSM at the macro–meso–field level in addition to ongoing national initiatives in different countries and by international organizations. A case study concerning the European Manufuture initiative is cited. The overall results conclude that RMfPA is a good ground for pursuing CSM. Necessary actions by stakeholders at different levels, spanning from policymakers to Industry, University and Research Institutes, are also discussed. CIRP, as a global academy, can play a relevant role at strategic, scientific and technological levels for the incoming global technological and industrial revolution: CSM.

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1. Introduction

Manufacturing is the backbone of industrialised society. From products, to processes sustaining product life cycles, to enterprises – across more than 23 sectors – manufacturing generates, directly and through services, wealth and jobs. Industrialisation of countries, since the beginning of the industrial revolution, has taken place through manufacturing. At the start of the industrial revolution, it was based on “small” networks within limited geographical domains and later on, on networks that exceeded first regional and, hence, national boundaries.

The first industrial revolution and consequent progressive world industrialisation, respectively, started and enabled long-lasting economic growth, then development, based on competitive innovation. This has lead to historically unprecedented economic growth and development. Such growth has affected and, in turn, been affected by, the economy, society environment and technology (ESET) context.

In the past two centuries, Industrialisation has spread from Europe, to the USA, to East Asia, to other world areas and it is still moving.

Economic growth, followed by economic development was the last century’s dominating paradigms. Most of the manufacturing policies and research and technological development (RTD) efforts were addressed to them. Growth was pursued with limited concern about environmental problems. In the 1960s, the “Club of Rome”, promoted the study, “The limits to growth” [1], thus “opening” the way to sustainable development (SD).

In the 1980s, SD – concerned with economical social and environmental development – was considered as the goal of a desired new industrial revolution, involving advanced as well as new emerging countries.

The incoming globalisation kept the focus on competitiveness and activated a different industrial revolution, leading to a new world distribution of production and markets. On one end, the new world can be seen as fierce competition among advanced and new be seen as fierce competition among advanced and new emerging countries. On the other hand, we all live on the same planet and share a common fate. Hence, there is an enormous amount of opportunity for countries to have deep intensive collaboration for
the common goal of improving the quality of life for mankind. To achieve our individual aspirations in a connected world, we call for a development that can be sustainable, within which competition and collaboration, two seemingly opposite forces, paradoxically balance for each entity's self-interest.

Further, besides globalisation, key challenges, such as climate change, ageing population, public health, poverty and social exclusion, loss of bio-diversity, increasing waste volume, soil loss and transport congestion, are dramatically arising.

Related economic, social and environmental problems are rapidly developing. A “desirable and acceptable future” dramatically calls for a development that is sustainable, within which competition can play an important role: global SD should be our vision. Its main enabler is a new paradigm: competitive sustainable manufacturing (CSM), whose high added value (HAV), is knowledge-based (K-b). CSM depends on and affects:

- manufacturing industry, i.e. products and services, processes, business models;
- the related education, research and technological development and innovation (E&RTD&I) system.

CSM should comply with advanced as well new emerging countries’ conflicting expectations and with ESET context requirements. CSM should be developed and implemented in each country and world region. Cooperation among countries and regions, particularly on sustainability, should take place.

The incoming global technological and industrial revolution (GT&IR) should be re-addressed and governed to develop, enable and support the new paradigm: CSM [2].

It is important to underline that world nations show [3] different levels of development, from economic growth to economic development and beyond.

This implies a progressive and articulated action towards

- emerging countries, for them to consider sustainability at the earliest stage of their process of growth/development;
- advanced countries, for a rapid move towards CSM.

Therefore, action may be similar for both, but the specific “components” are dependent on the country’s growth/development level. This leads us to consider specific solutions for emerging countries, not necessarily copying advanced countries.

The definition, promotion, implementation and evolution of CSM – to pursue SD and, hence, meet the key challenges – require

- A reference model for proactive action (RMfPA), such as that shown in Fig. 1 and described in Section 4.
- Strategic intelligence (SI), i.e. vision, strategic research agendas (SRAs), roadmaps, to propel and guide/govern such mechanisms.
- Human and financial resources.
- Infrastructures.
- Political will, within countries, whether advanced or emerging, to make such a move.

The main goals of the Key Note Paper are to

- Introduce and describe HAV, K-b, competitive sustainable manufacturing (CSM), as the enabler of sustainable development and, as such, the response to key challenges. Macro, meso and field level are considered.
- Present an RMfPA for the definition, promotion, implementation and evolution of CSM, at National and global levels.
- Present related ongoing activities and perspectives within international organizations, advanced (European Union, Japan, USA) and emerging countries (China), as determined from a survey carried out within the CIRP combined STC A/M/O Working Group on “Manufacturing Paradigms—Assessment and Future”.
- Propose actions by stakeholders concerned with CSM, i.e. from policy makers to public administrations and financial institutions, to industry, university and research institutes and centres.
- Make particular reference to CIRP’s strategic role, as a global leading academy.

To this end, following this introduction:

In Section 2, sustainable development is introduced as a global strategic vision that we should address to meet the economical, social, environmental, and technological challenges we face. SD should succeed the current dominating paradigm, i.e. economic development. Following the sustainability definition, some related relevant problems and solutions are presented. The role of technology is underlined. Studies and initiatives to foster SD, by advanced as well as emerging countries, are reported.

In Section 3, competitive sustainable manufacturing, as the main enabler of SD, is introduced. Historical and current data are reported. CSM concerns HAV, K-based products/services, processes and business models, ranging from macro to meso and field level. Competitiveness and sustainability are reviewed. Sustainability features for products/services, processes enterprises are presented.

In Section 4, the RMfPA to pursue CSM – thus sustaining SD and facing key challenges – is presented. It links CSM, i.e. SI, innovation and business cycles, to SD and key challenges.

Using this model, the ongoing SI generation process, and the role of E&RTD&I infrastructures, at macro level, has been surveyed within the assessed countries. CSM oriented paradigms and ETs at meso level, mainly from CIRP, are presented. The European Manufuture platform case is reported as a comprehensive case.

Finally, the move to global scale is presented.

The final section, conclusions and actions, deals with the main results and actions required to move towards CSM: the incoming global technological and industrial revolution.

2. Key global challenges and a proactive response: sustainable development

In this section sustainable development is introduced as a global strategic vision that we should address to meet the economic, social, environmental, and technological challenges we face. SD should succeed the current dominating paradigm, i.e. economic development. Following the sustainability definition, some related relevant problems and solutions are presented. The role of technology is underlined. Studies and initiatives to foster SD, by advanced as well as emerging countries, are reported.

2.1. Key challenges

Key challenges, as reported in major studies on world development, [4,5] are
• Globalisation.
• Climate change.
• Ageing population.
• Public health.
• Poverty and social exclusion.
• Loss of bio-diversity.
• Waste volumes.
• Soil loss and declining fertility.
• Transport congestion.

2.2. From economic to sustainable development

Throughout the last two centuries, ESET context changes have been acting as drivers and constraints, leading to the evolution of growth and development paradigms [2] as depicted in Fig. 2. It is important to underline that world nations show [3] different levels of development, from economic growth to economic development and beyond.

Sustainable development is emerging as a global strategic vision that we should address to meet the economical, social, environmental, and technological challenges we face.

SD is going back to political agendas, as awareness of its dramatic relevance to the world’s future is growing. Initiatives by public administrations (PAs) to foster the evolution towards SD are being carried out in various countries and world regions, impacting on innovation and business cycles as enablers of SD.

2.3. Sustainable development issues

Several definitions of sustainability have been proposed, over time. The World Commission on Environment and Development declaration [6] reads: “sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with the future as well as present needs”.

The analysis below can help us understand the full implication of the previous declaration and deals with some of the problems arising as well as potential solutions.

According to Seliger [7], sustainability is directed at enhancing human living standards while improving the availability of natural resources and ecosystems for future generations. More than half the global value created today is achieved by less than one tenth of the global population. Sustainable political, economic and social stability can only be achieved if mankind is able to create – worldwide and not only in the first world – jobs and living conditions of human dignity.

The exponential population growth [7] on the planet is endangering SD. A higher standard of living may increase this growth rate even further. For this to happen without exceeding ecological limits, the use productivity of resources must be raised (Fig. 3).

Engineering challenges derived from this requirement include the design of processes and products with improved usefulness and less negative environmental impact. Technology interpreted as science, systematically exploited for useful purposes, offers huge potential for contribution to this. Technology enables processes to transform natural resources into products to meet human needs. The interaction between research and education imposes dynamics on how creative solutions are developed for relevant tasks. Due to new means of transport and communication, knowledge and value creation is no longer limited to niches of wealth but is more and more accessible by everyone, everywhere at anytime. These dynamics must be mastered by management, considering chances for cooperation and risks of competition. Different societal frames with different value systems – considering economic, ecological and sociopolitical issues in different regions of the globe – have to be taken into account (Fig. 4).
About one quarter of the earth’s surface, accounting for 11.3 billion hectares, can be considered as biologically productive area contributing to the regeneration of resources. The average amount of biocapacity per capita on earth is calculated, in Fig. 5, by dividing the productive area by the number of people on earth. This results in 1.8 global hectares biocapacity per capita. The calculation for several countries shows how the ecological footprint mostly exceeds the biological capacity. The diagram curves show humanity’s total ecological footprint and the respective CO₂ portion of it from 1961 to 2003. Since 1985, resource consumption on a global level has been higher than the ecological capacity. For 2050, the required biocapacity of two Earths is estimated to be necessary, to satisfy the need for renewable natural resources.

A similar situation appears regarding non-renewable resources. Due to the consumption and limited availability of natural resources, material prices are increasing rapidly. In Fig. 6, the estimated coverage for selected materials is shown in combination with the price trend. For example, estimations on oil resources range between 1 billion and 3 billion barrels, and peak oil – the time from when oil production remains constant or decreases – is estimated between today and the year 2020. Although there are uncertainties about the exact time when each resource is consumed totally, the fundamental circumstances are indubitable.

Global economy, currently, is growing strongly. Technological improvements as well as liberalization of global markets will lead to an estimated doubling of the world’s gross national product within the next 25 years to more than 60 trillion US Dollars. Particular attention is brought to the so-called BRIC Nations: Brazil, Russia, India and China, whose stock markets achieved value advances of 100–300% in the last 5 years. Regarding the gross domestic product, the BRIC Nations will outrun the G8 Nations, except the USA, within 30 years. This raises the question of by which production technologies these growth rates will be managed in an environmentally responsible way.

The equal distribution of and access to resources, prosperity, rights, responsibilities, influence and voting possibilities poses a further challenge. Half of the world’s population today has to live with less than 2 dollars a day, without a telephone, without electricity. One fifth of the human race has more than four fifth of the global wealth at its disposal, while 200 million children starve. Inequality, for example in wages for female employees, can also be found in the industrialised nations in the OECD. The access to education in many countries correlates with their citizens’ social backgrounds. The course of the accumulated wealth of a society, from the poorest to the richest, is described by the Lorenz curve. The equity factor provides a term for the distribution of wealth in a society (Fig. 7).

The United Nations forecasts a world population of 9.5 billion people before the year 2050. The industrialised world of Europe, North America, Japan, Korea, Australia and a few more nations consists of less than 1 billion people. China with 1.3 billion people and India with 1.1 billion people, as well as other countries, strive to close the gap between them and the first world. If the lifestyle of these rapidly advancing nations becomes shaped by the predominant technologies of the first world, then the global resource consumption will exceed every ecologically, economically and socially responsible level.

Hence a sustainable political, economical and social stability can only be achieved if mankind is able to create worldwide and not only in the first world jobs and living conditions of human dignity.

2.4. Sustainable development initiatives

PAs, at national and regional levels, and other international organizations have and are promoting/managing initiatives concerning sustainable development/competitiveness, as summarized below.

The activities of the division for sustainable development (DSD) – within the United Nations Department of Economic and Social Affairs – are concerned with clusters of issues [9], such as “energy for sustainable development, industrial development, air pollution/atmosphere and climate change”.

The OECD is helping member countries make their development sustainable by ensuring a better balance between economic, environmental and social goals when developing policy as well as a long-term perspective on the consequences of today’s activities [10]. OECD countries, because of their weight in the global economy and environment, bear a special responsibility, historically, and for leadership on sustainable development worldwide.

Sustainable development is the overarching long-term goal of the European Union set out in the Treaty. The European Council,
which set out a strategy in 2001 for moving toward this goal, adopted, in 2006, a renewed sustainable development strategy that sets out a single, coherent plan [11]. It consists of seven key challenges which must be tackled if Europe is to move along a sustainable development path and maintain current levels of prosperity and welfare.

Recently, joint programming [12] has been promoted by the EC to address, through research and technological development, key challenges, that require a response at European if not global level. The ambition of the Commission is to allow cross-border research on these strategic areas by identifying common objectives and developing and implementing common research agenda.

Since the early 1990s, environmental protection has become an increasingly important area of Japan's national and international policies and programs. Japan Council for Sustainable Development [13] was created as the first mechanism calling for policy dialogues among multi-stakeholders in order to attain sustainable development. It has been very active and effective.

At the United Nations Conference on Environment and Development in 1992, [14] the United States agreed to develop and implement a national sustainable development strategy in order to integrate environmental matters into national decision-making. The President's Council on Sustainable Development provided the basis for such a strategy through a rich variety of policy recommendations.

The beginning of the sustainable development process in China was marked by the "White Paper on China's Population, Environment and Development in the 21st Century" [15]. Such a platform document for guiding the country's social and economic development was followed by a program, based on past achievements and experience. This, taking into account new requirements for sustainable development in the new century, specifies the objectives, principles, priority areas and safeguard measures for the country's sustainable development in the early 21st century.

2.5. Conclusions

Key challenges are increasingly driving the evolution of growth/development paradigms within nations. Although these may be at different evolutionary stages, sustainability is playing a rising, impacting role. Problems – such as our ecological footprint overshooting Earth's capacity – are strong drivers and call for solutions involving the ESET context. Manufacturing can greatly contribute to these solutions. SD is returning to various political agendas. International Institutions as well as PAs of the countries considered for our survey are strongly addressing sustainable development. This constitutes a driving factor for pursuing CSM.

3. Competitive sustainable manufacturing: the sustainable development enabler

In this section, competitive sustainable manufacturing – as main enabler of SD – is introduced. Historical and current data are reported. CSM concerns HAV, K-based products/services, processes and business models, encompassing from macro, to meso and field level. Competitiveness and sustainability are reviewed. Sustainability features for products/services, processes enterprises are presented.

3.1. Manufacturing, competitiveness and sustainability

Manufacturing industry has great relevance in modern history. The first industrial revolution – based on the manufacturing industry – was a divide between "ancient and new worlds". And, as such, it is a fundamental part of the first Kondratiev long wave [16] that depicts economic development related, but not exclusively, to technological innovations.

Since then, the manufacturing industry has generated wealth, jobs and quality of life, while promoting and sustaining services, education, research and development. Fig. 8 shows a 250-year view of industrial output by major countries [17]. Globalisation is injecting the new tremendous industrial production capability of countries like China, Japan and India. The consequence is that for the last two decades, human beings, no matter where they are, are enjoying the extra manufacturing output capabilities with relative low inflation. In the meantime, it also causes the dislocation of some production capabilities in the developed countries that have...
the same type of products or products that can be alternatives to similar products made in developing countries [17].

Specifically, we are at the dawn of the fifth Kondratiev long wave [16], within which a new technological and industrial revolution, on a global scale, is going to take place. This concerns all manufacturing sectors (see Fig. 9) from products, to processes and companies—and related E&RTD&I activities and “actors”.

Manufacturing can be studied in three levels: macro (macro-economics) to meso (production and consumption paradigms) to field level (products/services, processes, business models).

As introduced before, Manufacturing is a fundamental enabler of SD. It is strictly related to economy, society, environment and technology. Fig. 9 shows manufacturing sectors, following Pavitts classification [18].

World merchandise trade volume by major product group (1950–2006) is shown in Fig. 10. Sectoral structure of merchandise exports (2006) is depicted in Fig. 11.

Manufacturing involves a large variety of stakeholders, from policy makers and PAs, to financial institutions, to industry, to the E&RTD&I system.

This makes up the knowledge triangle (K-T) that refers to the interaction between research, education and innovation, which are key drivers of a knowledge-based society [20].

As said before, in the 1990s, following the SD vision, there was a move towards a sustainable manufacturing paradigm [21]. Due to strong focus on competitiveness and profitability that was then characterizing, emerging globalisation, sustainability was, somehow, set apart.

Now, key challenges are returning SD to political agendas. The necessary competitiveness and sustainability should be achieved by developing and implementing new HAV, K-based products and services, processes, companies and business models.

3.1.1. Competitiveness

In broad terms, competitiveness may be dealt with as market success at country, industry and company level. 

Competitiveness at country level was introduced by Porter [22]. In his basic work on the competitive advantage of nations, Porter identified nations’ competitiveness as based on the productivity with which they produce goods and services. Competitiveness is of paramount importance for implementing CSM. This emerges, clearly, from the various approaches used to assess it [23].

Competitiveness at meso level may be seen as a comparative concept of the ability and performance of a supply paradigm to respond to a demand paradigm [21].

Competitiveness at field level may be defined as a comparative concept [2], i.e. the ability and performance of an actor (firms, universities, institutes and research centres, etc.) to respond to a “customer demand” better than anyone else.

3.1.2. Sustainability

This is a broad concept, concerning three domains, i.e. economy, society, environment, and their interactions, as shown in Fig. 13. Sustainability at macro level would rely on environment, as the necessary basis, requiring economy, as the enabling tool to aim at the social dimension.

The European Commission defined a set of indicators for monitoring the implementation of the strategy for sustainable development. Its primary aim is to survey the current state of play in the implementation of the strategy [24].

The trends derived from the analysis of indicators [25] are assessed against policy objectives to inform the general public and decision-makers about achievements, trade-offs and failures.
in attaining the commonly agreed objectives of sustainable development.

Sustainability at meso level deals with appropriate response paradigms, concerning products and services, processes and business models that meet the aforementioned economical, social and environmental conditions. Sustainable manufacturing must respond to

- economical challenges, by producing wealth and new services ensuring development and competitiveness through time;
- environmental challenges, by promoting minimal use of natural resources (in particular non-renewable) and managing them in the best possible way while reducing environmental impact;
- social challenges, by promoting social development and improved quality of life through renewed quality of wealth and jobs.

At field level, products and services must be [26]

- safe and ecologically sound throughout their life cycle;
- as appropriate, designed to be durable, repairable, readily recycled, compostable, or easily biodegradable;
- produced and packaged using minimal amounts of most environmentally benign materials and energy.

The concept of sustainable quality (SQ) [27] should be used, see Fig. 14.

Processes must be designed and operated so that [26]

- wastes and ecologically incompatible by-products are continuously reduced, eliminated or recycled on-site;
- chemical substances or physical agents and conditions that present hazards to human health or the environment are continuously eliminated;
- energy and materials are conserved, and the forms of energy and materials used are most appropriate for the desired ends;
- work spaces are designed to continuously minimize or eliminate chemical, ergonomic and physical hazards.

The concept of product–processes life cycle (LC) matrix [27] should be used (see Fig. 15).

Social effectiveness of workers [26]

- they are valued and their work is organized to conserve and enhance their efficiency and creativity;
- their security and well-being is a priority;
- they are encouraged and helped to continuously develop their talents and capacities;
- their input to and participation in the decision making process is openly accepted.

For the business enterprise sustainable development means adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today, while protecting, sustaining and enhancing the human and natural resources that will be needed in the future [29].

The economic paradigm of product sales with profit generation through cost reduction by large quantities is challenged by the provision of functionality on location, at the time when needed and with the specification as required. Modern Information and Communication Technologies (ICT) enable real time access to requirements and availabilities, in order to logically control the provision of utilities. The adherence to quality demands is monitored by the ICT and enables demand-driven maintenance.

Sustainability at company level concerns specific products, services and business models. They should be developed, by the stakeholders concerned, complying with the CSM paradigm. Development of sustainable products and services, processes
and business models at company level, see Fig. 16, may rely on assessment methodologies and tools, as discussed in Section 3.2.

Elkington [31], in considering enterprises, introduced the ‘triple bottom line’ concept. This refers to satisfaction of not just the long-recognised bottom line of meeting economic goals (profits) but also the need to now simultaneously meet environmental and social goals (or ‘bottom lines’) in carrying out business. Sustainable value creation is the key contribution of corporations to sustainability; that is, to create long-term value on an economically, socially and environmentally sustainable basis.

In the global economy companies concentrate on their core competencies to remain competitive and cooperate in networks of value creation to meet customer demands. Communication among global partners with respect to sustainability in the sense of economic, ecological and social criteria can be enabled and enforced by a common understanding of sustainable value-creating modules. Fig. 17 presents the architecture of such a module as a node in a value-creating network.

Products are realized in processes performed by production facilities according to organizational aspects of where and when under human activity and supervision. The useful functionality is permanently evaluated and improved according to investment, costs and profitability, to resource effectiveness and efficiency, to health and education, qualification and creativity as criteria of sustainability. Sustainable value-creating modules [8] offer an opportunity to change from a profit oriented shareholder paradigm to a more sustainability oriented stakeholder paradigm. Finally, as shown by Hargroves and Smith [32], sustainability and competitiveness may get together since:

- widespread untapped potential resource productivity improvements may be made and coupled with effective design;
- a significant shift has been made in understanding what creates lasting competitiveness of the firm;
- a critical mass of enabling technologies in eco-innovations is available. These make integrated approaches to sustainable development economically viable;
- a growing understanding of the multiple benefits of valuing social and natural capital, for both moral and economic reasons, is taking place along with their inclusion in measures of national well-being;
- mounting evidence is showing that a transition to a sustainable economy, if done wisely, may not harm economic growth significantly, and could even help it;
- research by Spangenberg [33] shows that the transition, if focused on improving resource productivity, will lead to higher economic growth than business as usual, while at the same time reducing pressures on the environment and enhancing employment.

3.2. Evolution towards CSM

Key challenges and related problems, within the ESET context, are setting higher and higher competitiveness and sustainability targets to be met by manufacturing, at macro, meso and field level. Products/services, processes and business models must, then, innovate to comply with such targets. To achieve these, more and more Education & RTD & Industrial Innovation are of paramount relevance. Hence, CSM is based on the science – technology industrial innovation – market value chain, i.e. the integration of innovation and business cycles (Fig. 1).

This is a transformation of industry that must be supported – particularly, but not exclusively, within advanced countries – by the E&RTD&I system, which, in turn, should become more and more robust and effective, competitive and sustainable, while becoming global.

The activation, implementation, governance and effectiveness of such value chains require: from a mechanism for action, to a rolling process which covers everything from monitoring to generating new SI for evolutionary action to the involvement of all stakeholders, to investment in human and financial resources, to a strong interaction with the globalising E&RTD&I System.

This is an evolutionary cycle that involves a broader set of actors than conventional stakeholders, and requires a complex supporting mechanism, integrating SI life cycle and innovation and business cycles (see Section 5).

The new paradigm, CSM, as a response to “challenges” should be developed and implemented:

- at various levels, from macro to field level;
- within different economic, social, environmental, technological conditions;
involving, at various levels, all the stakeholders: from PAs, to
financial institutions, to industry, academia and research institutes.

A model of such a complex “space” is given by Yoshikawa: see
Fig. 18.

3.3. Conclusions

Manufacturing, as a wealth producer, job generator, human and
physical resources user is the backbone of countries’ growth
development. Figures support this. Manufacturing sustainability
and competitiveness, from macro to field level, is mandatory. High
targets must be pursued. E&RTD&I activities can help in reaching
the high level targets required.

4. Pursuing CSM: the global technological and industrial
revolution

In this section, an RMfPA to pursue CSM – thus sustaining SD
and facing key challenges – is presented. It links CSM, i.e. SI,
innovation and business cycles; to SD and key challenges.

Using it, the ongoing SI generation process, the role of E&RTD&I
infrastructures, at macro level, has been surveyed – within the
assessed countries – and it is discussed. CSM oriented paradigms and
ETs at meso level, mainly from CIRP, are presented. The European
Manufuture platform case is reported as a comprehensive case.

Finally, the move to global scale is presented.

4.1. Reference model for proactive action, linking CSM (SI, innovation
and business cycles) to sustainable development and key challenges

The proactive definition, promotion, implementation and
evolution of CSM to pursue SD and, hence, meet the key challenges,
requires

- A reference model for proactive action that refers to current and
  proactive ESET context perspectives.
- Strategic intelligence, i.e. vision, a strategic research agenda,
  roadmaps, to propel and guide/govern such a mechanism.
- Human and financial resources.
- Infrastructures.
- Political will, within countries, whether advanced or emerging,
  to make such a move.

The RMfPA is shown in Fig. 1.

RMfPA links CSM (SI, innovation and business cycles) to SD and,
hence, to key challenges. It is “driven” by SI and proactively “faces”
key challenges,

RMfPA may be described considering interconnected blocks. RMfPA is, by no means, linear.

Strategic intelligence, i.e. from visions, to SRAs, to Roadmaps is
generated, diffused, adopted and used by the stakeholders concerned
with CSM, i.e. PAs, financial institutions, industry, university, and
research institutes. It must be used by the stakeholders, as follows:

PAs invest in E&RTD&I, taking into account strategic intelligence
oriented to CSM. The triple helix approach, influence industry and
academia to move towards CSM.

Other stakeholders – from industry to universities, research
institutes and centres – by adopting such SI, whether investing
their own money and/or being supported by external finance, are
moving towards CSM. Hence the SI generation, diffusion adoption
and use process may be seen as a “governance tool” for moving
towards CSM.

Response of SD to key challenges: this may be achieved, as the
overall process is driven by SI.

“Main body” of RMfPA:

- It has been developed starting from Schumpeter theory, which
  states that economic development depends on clusters of
  Innovations, concerning new products (goods), new processes
  (production processes), new markets, new sources of supply of
  new materials and new organization.
- It is consistent with the manufacturing definition, i.e. products
  and services, processes, enterprises and business models.
- It refers to Kondratiev long waves (KLW). Kondratieff showed
  that economic growth moves as “long waves”. They refer to new
  technological as well as, social paradigms. We are at the dawn of
  the fifth KLW.
- It relies on the knowledge (K) generation, diffusion, use process,
  that integrates innovation and business cycles, ranging from
  science to market.
- It complies with the economy, society, environment and
  technology context and related key challenges.

RMfPA connects:

- the driving “force” of SI process (generation, diffusion, adoption
  and use) to innovation and business cycles,
- innovation cycles, where particularly PAs and their programmes
  and initiatives (K-process Infrastructures), promote and sustain, at
various levels, E&RTD&I activities, i.e. knowledge generation and diffusion,
• to business cycles, based on trunk innovations (infrastructures) and technological innovations, as K-adoption and use, mainly enabling technologies (ETs),
• to manufacturing paradigms, and
• finally, to the development paradigm, i.e. SD paradigm as in our case.

Four interlinked levels of intervention should be considered:

• world;
• national;
• regional;
• field.

Finally, to pursue SD

• CSM must be developed and implemented, in each country and world region.
• Cooperation among countries and regions must take place, particularly on sustainability.

4.2. The mechanism to develop implement and evolve CSM: ongoing activities

Proactive actions by stakeholders towards CSM are already going on in advanced as well as emerging countries. Activities show different levels of advancements, but suggest a common underlying country reference model for proactive action (c-RMfPA).

Assuming that the proposed mechanism would underlay activities within different countries and institutions, a survey of current activities in EU, Japan, USA and China, has been carried out considering:

• SI generation – diffusion – use process.
• The role of RTD&I infrastructures.
• The K generation – diffusion – use process.

4.2.1. SI generation – diffusion – use process. Strategic intelligence, i.e. from visions, to SRAs, to Roadmaps, is generated, diffused, adopted and used by the stakeholders’ concerned with CSM, i.e. PAs, financial institutions, industry, university, research institutes.

The distribution of roles may be different in each country/region, but the same basic mechanism is used.

Table 1 shows how the above process is being carried out in the countries analysed, i.e. European Union, Japan, USA and China, by the stakeholders involved.

4.2.2. Macro level: RTD&I infrastructures activities. Our survey shows that, at macro level, international institutions, such as OECD and UNEP, and PAs in the surveyed countries – acting as infrastructures – are carrying out studies and activities related to CSM.

Main ongoing activities are reported below.

OECD is working on environmental policy in the area of sustainable production. This work includes corporate behaviour and environmental policy; the role of government incentives to the uptake of environmental management systems; the need for different regimes for small medium-sized enterprises (SMEs). Public incentives to corporate environment-related research and development (R&D) and innovation are being assessed [10].

UNEP is significantly contributing to the body of knowledge and experience concerning tools and methodologies for the implementation of the sustainable consumption and production concept.

Its core mission is to identify new strategies and approaches for realigning current patterns with an eye to supporting local demonstration and pilot efforts for testing and then packaging results for broader transfusion globally [3].

The European Union sustainable development strategy [5] encompasses everything from promoting sustainable consumption and production to sustaining a move to CSM through the 7th Framework Programme, within – but not exclusively – the ‘Nanosciences, Nanotechnologies, Materials and new Production Technologies (NMP)’ theme. The core objective of the latter is to
improve the competitiveness of European industry and generate the knowledge needed to transform it from a resource-intensive to a knowledge-intensive industry, addressing the needs identified by the different European Technology Platforms [35]. The Manufuture Platform is making a fundamental contribution, oriented to CSM.

EUREKA [36] is an intergovernmental initiative acting at European level. Its mission is to increase the competitiveness of European industry by supporting close-to-market industrial R&D. EUREKA is recognized as a focal point for industry-led innovation in Europe, with a strong international dimension. The new EUREKA strategic document [37] fosters cooperation not only with the 7th Framework Programme but also with the Joint Technology Initiatives and European Technology Platforms [38].

The Japanese government released its Third S&T Basic Plan to cover S&T policies during 2006–2010 [39]. In order to maximize national potential and create a competitive nation that achieves sustainable growth, the Plan underscores the necessity to achieve sustainable economic growth based on environmental protection and the constant creation of innovation, in particular through the transformation in the world's top manufacturing nation and the enhancement of industrial competitiveness to win in global Science and Technology (S&T) competition.

CSTP, the highest body for S&T policies, deliberated that strategic promotion areas should include energy, manufacturing technologies, social infrastructure, and emerging frontiers [40]. METI manufacturing policy is to increase the level of productivity in manufacturing industries, by switching from a manufacturing-oriented “single engine” to a “twin engine” of manufacturing and service industries, rather than shifting its axis from manufacturing to service industries [41].

AIST formulated the medium-term plan of the second period research strategy based upon the concept of “minimal manufacturing” [42], (see Section 3.2). Substantiation of this concept, which is unfolding within “full research” [34], is expected to promote industrial reform in Japan and contribute to research and development related to the strengthening and fostering of manufacturing industries.

In the USA, the Department of Commerce launched the “Manufacturing Initiative” [42], whose goal was to develop a strategy designed to foster US competitiveness in manufacturing and stronger economic growth at home and abroad.

Consequently, the US Federal Government has established a Manufacturing and Services Assistant, a Manufacturing Council, Interagency Working Group on Manufacturing R&D (IWGRD) to identify and integrate R&D requirements and to develop strategies for the Federal Government’s Manufacturing R&D Programs.

IWGRD initially selected three technology priority areas: nanomanufacturing, intelligent & integrated manufacturing and manufacturing for the hydrogen economy; to form the basis for a coordinated, multi-agency focus on manufacturing R&D. These topics are each aligned with an existing national initiative. IWGRD is currently developing a report on Manufacturing R&D that further articulates the Federal Government’s role in each of the above areas.

In order to offer effective and continued support to US industry in its sustainable manufacturing efforts, the Department of Commerce is carrying out a public–private dialogue that aims to identify US industry’s most pressing sustainable manufacturing challenges and ways for the public and private sector to work together to address such challenges. The Environmental Protection Agency – while fostering an integrated and systems-based approach to achieving sustainability – focuses on six broad research themes as renewable resource systems, non-renewable resource systems, long-term chemical and biological impacts, human-built systems and land use, economics and human behaviour and information and decision making.

China has set out its development policy guidelines in the 2006 Five Year Plan [43] which, while acknowledging that economic reform, growth, and development will continue at a high rate, now places emphasis on the development of a harmonious society in which more consideration is given to the social implications that are associated with rapid economic development.

The 2006 Five Year Plan contains strategic priorities based on the concept of ‘scientific development’ to ensure that GDP growth goes hand-in-hand with improvements in employment, social security, poverty reduction, education, healthcare, and environmental protection. The protection of resources and the preservation of the ecological environment will take place through the promotion of resource-efficiency and environmental sustainability, energy-saving initiatives, and the development of the ‘circular’ economy through recycling.

Chinese policy makers increasingly see environmental protection as a major challenge and China has an important global role to play in this field. The dialogue on environmental issues, which covers sustainable development, climate change, and renewable energy, was recently upgraded to ministerial level.

A law on cleaner production was approved in 2002. It enforces the continuous application of measures for design improvement, utilization of clean energy and raw materials, the implementation of advanced processes, technologies and equipment, improvement of management and comprehensive utilization of resources to reduce pollution at source, enhance the rates of resource utilization efficiency, reduce or avoid pollution generation and discharge in the course of production, provision of services and product use, so as to decrease harm to the health of human beings and the environment. It is the policy of the nation to encourage scientific research, technical development and international cooperation to develop cleaner production.

The above analysis shows

- commitment, at national level, addressed somehow at CSM and
- “embedded” availability for international cooperation.

These are a good foundation for a move towards globalising CSM (see Section 5).

4.2.3. Meso level: generating new paradigms and enabling technologies which address CSM. CSM pursuit requires generation, diffusion, use of response paradigms and related ETs, with regards to:

- products-services;
- processes, implementing products-services life cycles, and their life cycles;
- enterprises LC and related business models: ensuring competitiveness and sustainability.

The analysis carried out concerns the K-generation phase and concentrates on CIRP activities.

Studies and results are reported hereafter. Studies on sustainable production (SP), the forefather of CSM, started in the 1990s. Alting and Jorgensens [44] introduced the LC concept as a basis for sustainable industrial production.

Jovane [21] developed the “dynamic model of the SP paradigm”. According to this model, the product-processes LC matrix evolution should be driven by the ESET context, while RTD&I activities should act as enablers of such evolution. This concept was then applied at company level and the Manufacturing model [45,46] was developed. This was adopted by an Industrial Group to develop its next generation manufacturing system [47]. Later the Manufuture concept, based on science innovation market value chain, encompassing from micro to meso to field level, was introduced [48].

Tomiyama [49] proposed the post mass production paradigm (PMPP) as a system of economic activity, capable of encouraging and sustaining economic growth without depending on mass production and mass consumption of artefacts. PMPP, by proposing better engineering and manufacturing technologies, would allow the continuation of manufacturing activity and economic growth, but reducing production and
consumption volume of artefacts to an adequate manageable size, balancing it with natural, social, and human constraints. PMPP may be seen as a way of overcoming the modern “evils” by decoupling economic growth from resource/energy consumption and waste creation, thus pursuing global sustainability. For Yoshikawa [34] sustainability requires integration of manufacturing and inverse manufacturing, i.e. closed loop manufacturing. Fig. 19 shows the evolution of the concept. As for the products, Yoshikawa states that

- what people value is not a product itself, but its functionality;
- functionality of a product is service embedded in the product. (People receive the service someone embedded in the product when they use the product);
- latent functionality appears as service when the product is used;
- functionality of a product decreases when it is used. Functionality = ∑ services (life of a product terminates when services embedded are exhausted).

The potential value of a product may be measured by functionality, i.e. the total amount of service available. Hence, closed loop manufacturing covers everything from construction to functionality, i.e. the total amount of service available. Hence, closed loop manufacturing covers everything from construction to functionality, extraction and dissolution of functionality. Within this frame Yoshikawa introduces the minimal manufacturing and maximal servicing paradigm for sustainability (Fig. 20).

Following the above, sustainable manufacturing is a manufacturing system that produces value. Considering that total value is given by the sum of both: natural value: space, functionality of eco-system (eco-system services), mineral resources, energy, bio resources and artificial value: primitive services potential, functionality of material, functionality of products. Sustainable manufacturing increase the total value by means of minimal manufacturing and maximal servicing is the sustainability paradigm proposed by Yoshikawa.

Referring to services, Ueda and Takenaka [50] state that the nature of services differs from that of manufacturing. Interest in human behaviour (lifestyle, cognition, brain function, etc.), concerns about social or environmental sustainability, and scientific exploration in innovation or service design all might expose uncertainty about objectives or environments of services in the real world.

Toward the co-creation of new values in services, it is important to design how decision-making agents mutually interact and to understand the system uncertainty. Emergent synthetic approaches using emergent-based computations, experimental economics, and experimental psychology are thought to be useful approaches to create new service values.

Science and technology are expected to establish a new scientific methodology for studies of services to raise service-sector productivity and to support new services. Westkamper et al. [51] dealing with LC management and assessment, outline the emergence of approaches and visions towards sustainable manufacturing. Starting from the need of sustainability emerging from ESET contexts, they show that a product LC approach leads to a new manufacturing paradigm (Fig. 21). Then they cover from manufacturing of sustainable products to the length of a product’s life, as compared to technical progress. As a fundamental factor for sustainability, a model of the product LC is proposed. It shows how and where the added value is generated (see Fig. 22).

Then, the LC management is seen as a holistic way to achieve products’ maximum performances (value) also in the light of sustainability (Fig. 23).

The development of quantitative environmental life cycle assessment (LCA) [52] methods provided necessary tools for design of products and systems with the lowest possible environmental impacts in the whole life cycle [53]. Based on the detailed LCAs, simplified eco-design tools were developed [54].

At the present time methodologies for social/societal LCA are under development so that managers/designers will have tools to quantify this important dimension of sustainability. This is a major step since it is difficult to deal with the social/societal dimension in a structured and transparent manner.

Today many companies, especially the larger ones, have made sustainability an integral part of their business concept and on the international level many of these companies are working together in various networks. This is a very important development driving the implementation of this new business development.

Mass customization (MC) is a paradigm for manufacturing that appeared in the 1960s and is slowly taking place among the different business models available today [55]. The concept of mass customization is attributed to Davis [56]. It was defined by Tseng and Jiao [57] as “producing goods and services to meet individual customer’s needs with near mass production efficiency”. Kaplan and Haenlein [58] contributed by calling it “a strategy that creates value by some form of company–customer interaction at the fabrication/assembly stage of the operations level to create customized products with production

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**Fig. 19.** Manufacturing actions for sustainable evolution [34].
cost and monetary price similar to those of mass-produced products’.

Until recently MC has been seen mainly as a new business model oriented to conquer some part of the consumer market. However the MC paradigm can also bring advantages to sustainable development by substantially reducing, considerably, energy and other resource consumption, and unsold items by eliminating products that are produced without customers in sights. But MC has rarely been used today primarily for larger improvement on SD. Lately it has been shown how MC can help SD and in fact it is possible to speak about a new paradigm called mass customization for sustainable development (MCSD) [59].

It has been shown that customization of products always brings advantages in sustainability just by taking into consideration the business model deriving from the mass customization paradigm that in the best cases is working on the make-to-order principle and therefore a strong reduction of unsold items typical of mass production’s old paradigm. Furthermore by designing for mass customization and also integrating sustainable development in the design phase, it is possible to move closer to a full sustainable manufacturing.

Sustainable materials should be selected or designed on the basis of the “cradle to cradle” principle [60], determining a complete redesign of the production process as well as of the well-assessed materials that have been used so far in every industry. Further, a third enabler is linked to the value network (VN), where innovations happen thanks to the active collaboration and distributed knowledge of partners inside and outside the company.

Manufacturing researchers from CIRP, as shown before, have successfully contributed to the development of new paradigms and ETs that address sustainability. Some late developments and perspectives, as shown by Westkämper [30], are synthesised in Fig. 24.

Manufacturing beyond state of the art follows the objectives to reduce the consumption of resources in the transformation process from input to output. Solutions for miniaturization of products, technical components and machines as well as the substitution of materialized functions by electronics and software are strong contributions to reduce the consumption of material and energy in the life cycle of products. The implementation of technical intelligence based on process-models has the potential to reduce scrap, waste and defective products. It is evident that there is no conflict of economic and ecologic objectives.

Manufacturing theories should be developed [61]. A theory of manufacturing should enable different views on holistic production systems, which must have an explanatory value and should permit the diagnosis, prognosis and design of production systems and their behaviour under the influence of the environment and objectives of sustainability.

Still, as proposed by Yoshikawa [34], new general paradigms – such as “energy productivity” that may challenge the current “labour productivity” paradigm – call for the development of new key technologies and, above all, a systematic theory, to support the
realization of sustainable manufacturing (Fig. 25). Resource efficiency in production technologies already calls for specific research activities [63].

It is urgent to concentrate on the development of basic concepts for sustainable technologies which seem quite different from the traditional manufacturing technologies. CIRP will be the best environment to discuss and promote their development, along with new emerging manufacturing and related E&RT&D&I system strategies.

4.3. The ongoing European initiative towards CSM—Manufuture: a case study

An interesting case is the European initiative towards CSM that relies on the European Manufuture Platform and related technological platforms (TPs). These have been promoted by the European Commission [35].

The European Manufuture Platform [62] has played a fundamental role in establishing the mechanism previously described. In the pursuit of CSM, it has developed and implemented:

- the SI (Vision 2020, SRA, Roadmaps) generation, diffusion adoption and use process, considering also its LC and governance [64], see Fig. 26,
- the “Manufuture framework”, see Table 2, that enables and supports the SI LC process [64], its LC and governance. The main features of “Manufuture framework” that enables and supports the SI LC process [64], and its governance are reported in Table 2.

SI generation, diffusion, adoption and use process, including its LC and governance, is the SI “rolling programme”, Fig. 26, that must be implemented to support HAV K-b innovation [65] of products/services, processes and business models. It plays the role of “support service on ground” to the aim of leadership of the SI towards concrete challenges ahead [66–69]. This is in line with the evolution loop for sustainability, proposed by Yoshikawa [34].

The SI “rolling programme” encompasses four complementary activities, which are innovative from traditional ones and life cycle oriented. They are cited below:

- Foresight: enables decision making on top down knowledge-based policies related to GT&IR [66–68].
- Roadmapping: operates at meso level producing priority areas for push and pull transectoral technology development with reference to HAV paradigm and sustainability [70].
- Implementation: operates at field level and builds priorities for interventions and plans to minimizing threats, maximizing opportunities and reducing risks for new HAV products/services, processes and business models.
- Monitoring: assessment and evaluation of the innovation process towards competitive sustainability.

The goal of the SI “rolling programme” is to track the progress towards turning knowledge into growth according to the evolution of paradigms (Fig. 1).

Fig. 27 shows the Manufuture reference model for proactive action. It concerns initiatives from basic to pilot, the latter being aimed at leading and accelerating the pursue of CSM. The previous analysis has shown that such a reference model for proactive action also holds, in general terms, in other countries.
Such a model, as shown in Fig. 27, relates:

- both Industrial and E&RTD&I internal markets becoming global;
- the role of public administrations, impacting at macro level on industry and academia, following the triple helix approach [64];
- the national E&RTD&I system, implementing education, research and innovation at field level;
- the strategic leading role of the polar star, diffusing the SI, i.e. Vision 2020, SRA and Roadmaps, developed by stakeholders and alike;
- the “leading” effect of the polar star on the actions of all stakeholders, i.e. PAs, at macro level; industry, university, research institutes, making up the IK-T, at field level, see Fig. 2;
- the consequent “convergence” of PAs programmes and initiatives and E&RTD&I (IK-T) projects (field level) towards the common strategic goal, i.e. CSM.

Because of the size and complexity of the transformation processes that concern European industry and the related E&RTD&I System, Manufacturing has been initiated as a cohesive driving force to address CSM.

Basic activities range from concerns with management, on a “rolling basis”, with SI and FW life cycles, to implementation of SI within FW, to monitoring and governance of the above processes, while interacting with the stakeholders, within the evolving ESET context.

Pilot activities, such as “lighthouse projects”, are intended to lead and accelerate the pursuit of CSM. As an example, the “factory as a product” is the first “lighthouse project” to be launched. Its
“rolling” master plan would cover from medium to medium short-term horizons and refer to FP7, Eranet, Eureka (ProFactory Umbrella and Manufacture Industry Cluster). Studies on a JTI, oriented to CSM, are under way.

Structural activities concern monitoring: on one side, PAs programmes and initiatives, European and national manufacturing related TPs and relevant single E&RTD&I projects; on the other side, evolution of the ESET context. This is necessary for governance and evaluation of the implementation level of SI and related impact.

4.4. Pursuing CSM at global level: the global technological and industrial revolution

Sustainable development is a global goal that, as such, must be pursued at national as well as sovranational level. The same goes for CSM.

It is important to acknowledge that the various world nations show different levels of development – from economic growth to economic development and further – as shown in Fig. 28.

This implies a progressive and articulated proactive action towards

- emerging countries, for them to consider sustainability at the earliest stage of their growth/development process;
- advanced countries, for a rapid move towards CSM.

The reference model for proactive action may be similar for both, but the specific “components” are dependent on the growth/development level. This leads us to consider specific solutions for emerging countries, not necessarily copying advanced countries.

In particular this refers to

- Infrastructures such as E&RTD&I programmes and initiatives.
- SI generation, diffusion, use process.

Table 2

| New paradigm: HAV K-b competitive sustainable manufacturing (CSM) | High level goal: Transformation of industry and related E&RTD&I system | Reference model for proactive action (basic activities and pilot actions) at European level, Fig. 26—where a converging role of stakeholders towards CSM is “helped” by a co-shared “leading” entity, i.e. the “evolving polar star”, diffusing SI |
| Governance of the domain of action, Fig. 26, based on governance of the SI (Vision 2020, SRA, Roadmaps) generation, diffusion, adoption and use process, considering also its life cycle |
| The stakeholder’s and the manufacturing knowledge innovation community (KIC) |

Fig. 28. Countries development stage and CSM goal.
K generation, diffusion, use process, in terms of potential new paradigms and ETs.

Assessment of strategic industrial perspectives and needs.

Fig. 28 shows how cooperation/integration may lead nations transforming themselves through time.

Cooperation/integration – to help national and, increasingly, supranational/global activities – and pilot actions should take place in the above domains. Their governance would be of paramount importance to achieve effectiveness.

A global reference model for proactive action (g-RMfPA) stems from the cooperation-integration of national activities within the aforementioned domains. g-RMfPA implies, supranational cooperation and, hopefully, integration. Several countries show programmes oriented to international cooperation, often related to sustainability. IMS is a good example.

The achievement of effectiveness and governance requires:

- Proactive behaviour by stakeholders at a global level.
- Cooperation and, possibly, coordination of the countries SI “rolling programmes”, which is shown in Fig. 29, as they are emerging.
- The establishment of an International Coordination Summit, mainly focusing on sustainability. This should be a highly strategic perspective.
- Cooperation/integration of Infrastructures such as E&RTD&I Programmes and Initiatives.
- Cooperation/integration of K generation, diffusion, use process, concerning potential new paradigms and ETs.
- Assessment of strategic industrial perspectives and needs.

Fig. 29 shows how cooperation/integration may lead nations transforming themselves through time.

The survey of the EU, Japan, the US and China, using the RMfPA, shows that the SI generation process is somehow established as well as the proactive role of E&RTD&I infrastructures. Further, at meso level, ongoing activities are generating paradigms and ETs for CSM.

Current conditions at country level, also proved by the European Manufuture case, can enable CSM pursuit at country level.

At global level such processes may take place but different growth development stages of countries must be considered. Coordination/integration of these may lead to “clouds” of countries moving at different “speeds” towards CSM. Governance of such a complex process is of paramount relevance for pursuing global CSM. CIRP could promote and foster appropriate actions.

5. General conclusions and actions

Key global challenges, concerning economy, society, environment and technology, and related problems are dramatically arising. A “desirable and acceptable future” urgently calls for a shift from economic to sustainable development. This is directed to enhancing human living standards while improving the availability of natural resources and ecosystems for future generations. Sustainable development, then, must be a global goal.

CSM is the main enabler of sustainable development (SD), as it generates wealth, sustains jobs (directly and through related services) and manages human and physical resources, from materials to energy. CSM concerns everything from macro to field level (products/services, processes, business models) and relies on the SI, innovation and business cycles value chain.

To achieve SD, CSM should be pursued, at country as well as global level. Countries show different growth/development paradigms; regardless, all nations should introduce sustainability. The trajectory to achieve CSM may differ from country to country, and vary in length of time to implement. Country pursuit of CSM and coordination/integration among countries, whenever possible, are mandatory for governance and effectiveness in the pursuit of national and global CSM.

A reference model for proactive action (RMfPA) for the definition, promotion, implementation and evolution of CSM – thus sustaining SD and facing key challenges – has been presented. It links CSM, i.e. SI, innovation and business cycles, to SD and key challenges. Already tested in the European Union context. It has been used to carry out the survey of ongoing initiatives and to propose actions.

The analysis carried out within the CIRP combined STC A/M/O Working Group on “Manufacturing Paradigms—Assessment and Future” covers, mainly, ongoing national and global activities.

- At macro level: studies, initiatives and mechanisms for action, by International Institutions and PAs in the European Union, Japan, USA and China, including SI generation, diffusion, use process.
- At meso, field level: K generation, diffusion, use process, related to CSM, concerning new paradigms, concepts, methodologies and tools, enabling technologies.

shows that there are good grounds and a sharable c-RMfPA, as proposed by this paper, for pursuing CSM at country level. At global level, some preliminary initiatives are taking off. The g-RMfPA,
previously presented, can contribute to establishing the required framework for action. At both levels, actions could and should be taken. Ongoing initiatives should be enhanced, coordinated/integrated and brought into governable and effective Action Plans, encompassing everything from SI life cycle to key challenges driving action. Such a move should be conceived, fostered and supported by Stakeholders. At macro level, policymakers, PAs and relevant institutions, should allocate human and financial resources, infrastructures, generation and use of SI, implementation of RMfPA according to the long term strategic interest. The global, as compared to country, situation requires further studies and special care. Following this paper, further studies and actions should be launched. CIRP, as a global academy, through its “strategic activities” could foster such studies and promote necessary initiatives, which seem quite different from the traditional manufacturing technologies. CIRP will be the best environment to discuss and promote their development, along with new emerging manufacturing technologies and related E&RT&D&I system strategies. At field level, the rapidly changing ESET context requires a highly reactive behaviour, integrated with the proactive behaviour requested as for above. CIRP members, singularly and as an academy, can and should play a relevant role, as they are directly involved in or somehow connected to all stakeholders along the science-innovation-industry-market value chain.

The pursuit of global competitive sustainable manufacturing should be the incoming global technological and industrial revolution.

Acknowledgments

The authors are pleased to acknowledge the contribution and dedicated work of Dr. Lorenzo Molinari Tosatti and Dr. Carlo Brondi, ITIA-CNRR.

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