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Virtual Global R&D Summit 2020
Building Resilient Economies through Technology and Innovation: Industry & Science Collaboration in the New World Order
Date: November 25 - 27, 2020
GLOBAL R&D SUMMIT 2020

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CHANGING PARADIGMS: INDIAN INNOVATION ECOSYSTEM

Background Paper for DST-FICCI, Global Research and Development Summit 2020

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CHANGING PARADIGMS: INDIAN INNOVATION ECOSYSTEM
Background Paper for Global Research and Development Summit 2020 25 – 27 November 2020, New Delhi

The Imperative of dedicated Indian Science and Technology Clusters

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1.0 INTRODUCTION

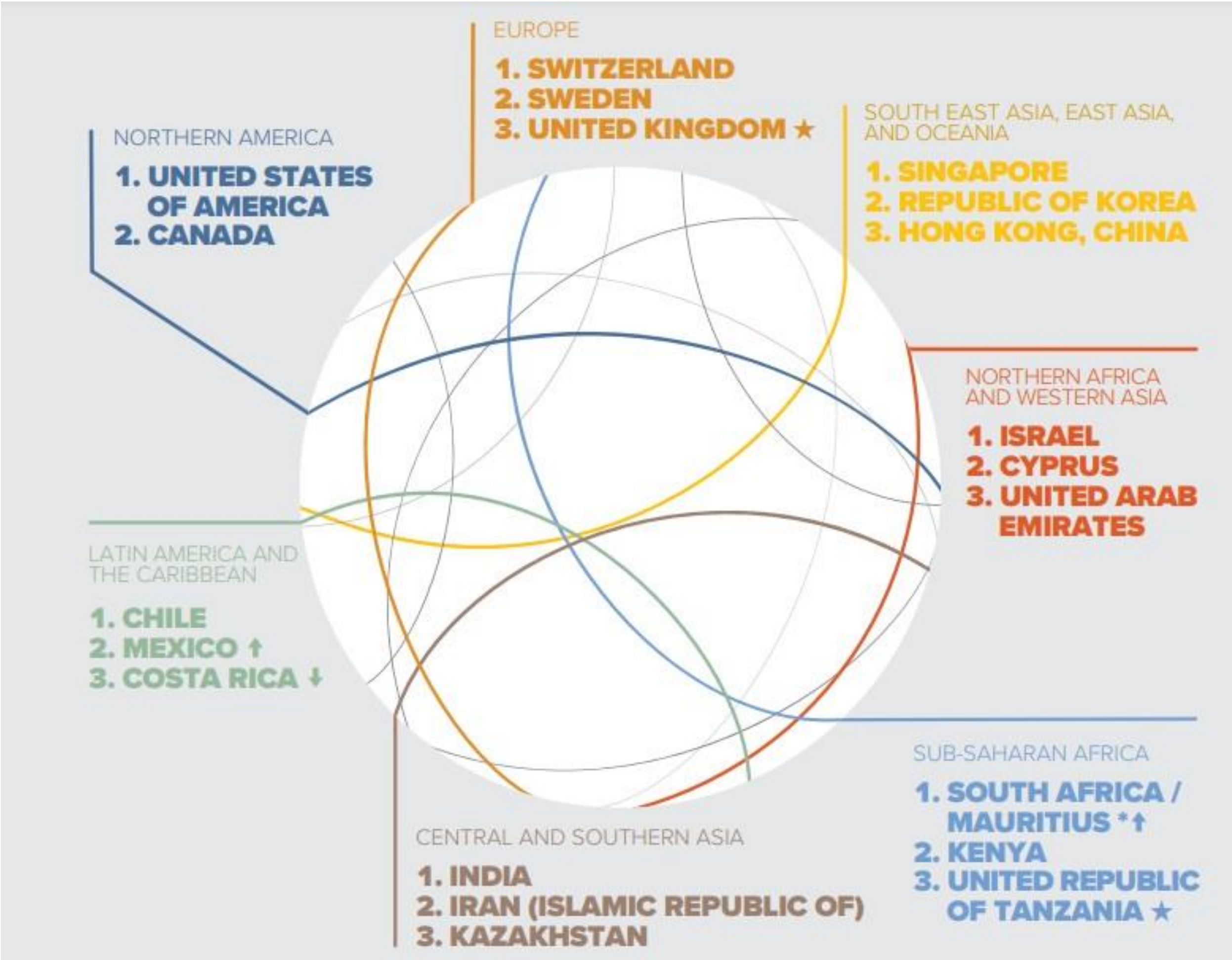
Innovation is the engine of growth that leads to the conversion of research ideas into technologies and products in the shortest possible time, and thereby creates jobs, economic growth and prosperity for a nation.

The Oslo Manual distinguishes between innovation as an outcome (an innovation) and the activities by which innovations come about (innovation activities). The latest edition defines an innovation as "a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)". (www.oecd.org › sti › inno › oslo-manual-2018-info)

Over the years, Innovation has become an extremely important parameter to measure a country's intellectual dynamism and competitive power in the industrialised world. In the Global Innovation Index (2020) Switzerland retains its pole position as the most innovative country for the 10th consecutive year, followed by Sweden USA, UK and Netherlands. The geography of innovation is also undergoing a major change, with countries such as India, China, the Philippines, and Vietnam making significant progress in their GII Innovation Ranking over time. All four countries have now broken into the top 50, with India in the 48th position. (www.wipo.int)

The nature of innovation activities in a country is an outcome of its policies, institutions, and the interplay between them (Lundvall, 1988). Formally called the National System of Innovation, this configuration is more commonly referred to today as the innovation ecosystem of a country.

The objective of this note is to outline some priorities and options to strengthen the Indian innovation ecosystem. We start by outlining the characteristics of the innovation ecosystems of some countries which are relevant to this objective.



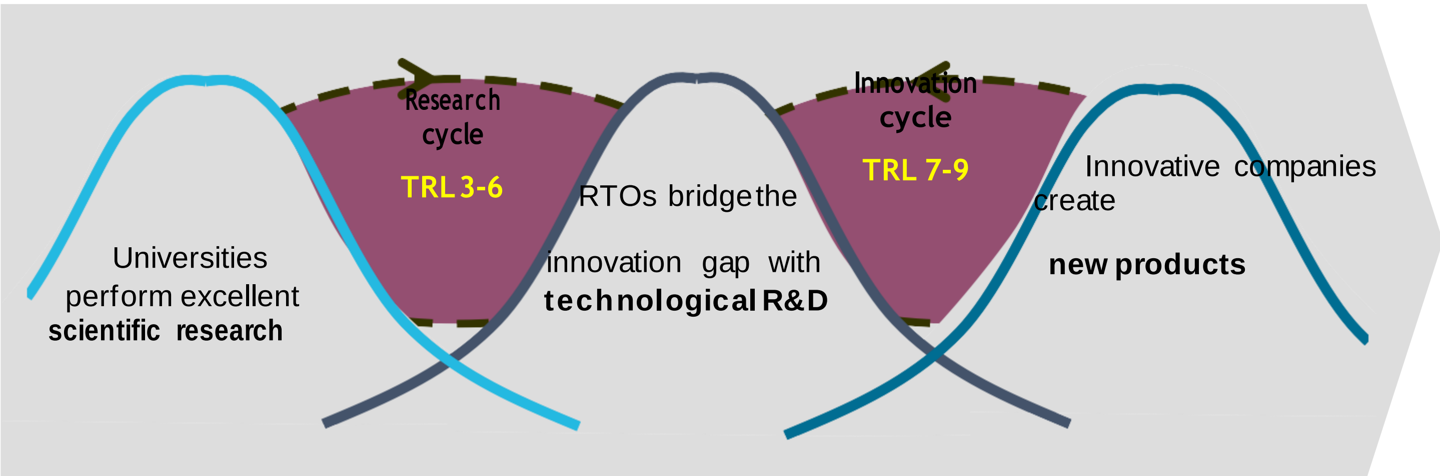
Source: WIPO GII report Chapter 1

1.1 Comparison of some select international research and Innovation Ecosystems

Switzerland is one of the most innovative nations is the world and has all the key characteristics required such as a well-trained work force, excellent academic institutions, fully developed infrastructure, diverse funding possibilities, freedom for creative thinking, a strong network, high R&D expenditures etc. The Industry in Switzerland contributes 2/3rd of the Swiss R&D Expenditure, while public funds are largely used for fundamental research. Swiss tier-one universities (i.e. 10 cantonal universities and Switzerland's two federal institutes of technology: ETH Zurich and EPF Lausanne) hold strong to very strong positions in international ranking lists. Switzerland has the second-highest per capita expenditure on education in the world (14,900 USD per year). Its total education expenditure corresponds to 5.6% of its GDP (2013). (www.swisnexx.org) . Switzerland also pursues a highly internationalised strategy of Innovation and research.

The German Science and Innovation Landscape is organised with characteristic efficiency and clarity in order to fast track innovation. Europe has, for the longest time, made Innovation its success mantra and secured its indelible position as a Technology Leader thereby creating huge dividends for its R&D and thereby multiplying employment and economic power for its constituencies. The ecosystem in Europe particularly Germany and Switzerland is extremely well evolved, with universities and research institutes that engage in fundamental research on the one side, and the Industry that invests in Innovation and R&D on the other hand, bridged by applied research institutions that compress the innovation cycle and bring products from lab to market in the shortest period of time.

At one end of the continuum, basic research is conducted through organisations like the Max Planck, Helmholtz as well as Institutes of Applied Science. At the other end of this continuum is the Industry as user of this knowledge, which creates products that are technologically superior, faster, cheaper and aligned with customer requirements. The process of leveraging the results of basic research and converting them into processes that achieve the needs of the Industry is taken on by applied research organisations such as Fraunhofer. While the Universities, and fundamental research organisations get up to 100% of their funding from the German Government, applied research organisations like Fraunhofer have to earn more than 2/3rd of their budgets from projects contracted by clients.



Source: Fraunhofer model of applied research in the German Innovation Landscape (Fraunhofer profile presentation)

The UK Research and Innovation (UKRI) is a quasi-autonomous non-governmental organisation of the (UK) that directs research and innovation funding, funded through the science budget of the Department for Business, Energy and Industrial Strategy (BEIS) (www.wikipedia.org). Earlier the Research Councils focussed on fundamental research and the connect to business was driven through Innovate UK and Catapult Centres. Since 1 April 2018, UKRI brings together seven existing research councils, Innovate UK and the Research and Knowledge Exchange functions of the Higher Education Funding Council for England (HEFCE) into one unified body. Working in partnership with universities, research organisations, businesses, charities and government its mission is to foster research and development within the United Kingdom and create a positive "impact" - "push the frontiers of human knowledge and understanding", "deliver economic impact" and "create social and cultural impact".

UKRI was created following a report by Sir Paul Nurse, the President of the Royal Society, who recommended the merger in order to increase integrative cross-disciplinary research. The Catapult Network (www.catapult.org.uk) brings together nine elite technology centres established by Innovate UK as a long-term investment in the UK's economic capability. Catapult units help industry to fast track the adoption and scaling up of new technologies and thus help create products and services that can compete in the global markets. They are equipped with cutting-edge R&D infrastructure, partnership-building and specialist knowledge and hence connect research to industry seamlessly.

China's science and technology ecosystem: A recent Study by Global Advantage Consulting provides insights into the intricate S&T ecosystem that has evolved over time. China's spending on R&D (as a percentage of GDP) has been increasingly steadily and Chinese industry invests heavily (as a percentage of GDP) on R&D.

The country has five key objectives in its 15-year (2006-2020) plan for scientific and technological development:

1. Raise the ratio of S&T development contributed to the economy to 60%
2. Raise GERD/GDP to 2.5% by 2020
3. Reduce reliance on foreign technology and IP to less than 30%
4. Be among the top five worldwide in domestic invention patents and international citations of scientific papers
5. Identify 11 key national economic and social development areas, focusing on the selection of 68 priority topics

Chinese universities are ranking higher globally as well. China now leads internationally in the number of science and engineering graduates with Bachelor's Degrees, and ranks third in science and engineering doctoral degree awards after the United States and Europe.
China's ambitious Belt and Road Initiative has S&T implications as well, some of which include (www.globaladvantageconsulting.com)
Establishing joint labs, science parks, international tech transfer centres, and S&T exchanges

- Constructing cross-border information and communication technologies and energy infrastructure
- Using satellites built for communication, navigation and remote-sensing to build a "Belt- and-Road spatial information corridor"
- Developing digital connectivity platforms

The United States does not have a single unified science policy. Instead, the **Science Policy of the United States** is the responsibility of many organizations throughout the federal government. Much of the large-scale policy is made through the legislative budget process of enacting the yearly federal budget, although there are other legislative issues that directly involve science, such as energy policy, climate change, and stem cell research. The US has consistently strengthened its science and technology ecosystem by focussing on some important policies: (www.oecd.org/sti/inno/2754226.pdf)

Firstly, science – including understanding-driven research, targeted basic research, and mission-directed research – must be given the opportunity to thrive, as it is the precursor to new and better understanding, products and processes.

Second, the role of the private sector is extremely critical in maintaining the overall scientific and engineering enterprise.

Thirdly, strengthening of the education system from Kindergarten to University and ensure that the human resource capital is leveraged.

Fourthly understanding that science has moved beyond boundaries and therefore the internationalisation of scientific and research cooperation must be encouraged.

Finally, the symbiotic relationship between science and society must be maintained. Not only it is enough to strengthen the scientific enterprise, but the ties between society and science must be fortified

The partnership of the US federal Government and the Universities has led to vital benefits for technological leapfrogging. The excellent infrastructure of Federal labs and research facilities coupled with the network of independent labs has ensured that both national priorities as well as industry's requirements are equally addressed.

In contrast to the countries discussed above, **India** has focussed on a strong academic and basic research capability, the outcomes of which are early stage discoveries (Technology Readiness Levels of 3-5). Hence most of its research coming from Labs and Universities still needs much more calibration and development before it is usable by the industry (Technology Readiness Levels of 7-9). India, which lacks dedicated applied research institutes, needs to accelerate the connect between its research and industry, in order to fast track development, adoption and deployment of new technologies to market.

2.0 THE INDIAN INNOVATION ECOSYSTEM

As one of us described it in a recent article, the Indian innovation ecosystem as it is today, is a mix of two different sets of characteristics—one set reflecting the strategic intent of creating a science-based innovation architecture along the lines of that found in advanced economies (Nair et al., 2015) and the other reflecting a home-grown frugal approach to meeting basic needs in a resource-scarce environment (Krishnan, 2010; Prahalad & Mashelkar, 2010). The former can be traced to early decisions made by the political leadership in the decade following Indian independence from the U.K. in 1947.

A Science Policy Resolution in 1958 declared that "It is an inherent obligation of a great country like India with its tradition of scholarship and original thinking, and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today" (Government of India, 1958). Over the next few decades, India set up networks of government-owned and operated laboratories for R&D in atomic energy, space, defense technologies, health, and agriculture apart from scientific and industrial research (Chopra, 2007; Nayar, 1983).

India has also contributed immensely to the concept and development of "Frugal Innovation". Impactful frugal innovation in India, is the outcome of: (a) a culture of improvisation built around a propensity to find solutions based on available resources; (b) a large prospective market where the identification of the right combination of price and functionality can cause demand to surge; (c) a price-sensitive yet open-minded mass of consumers; (d) gaps in service provision and extreme conditions creating a pent-up demand for low-cost products and services in areas of basic need; (e) an inclination toward service and business model innovation; (f) increasing availability of social funding at a low cost; and (g) increased emphasis of innovation policy on inclusivity and outcomes (NESTA, 2012). Over time, even the science-based innovation system created by the government has drawn on the frugal approach preferred by the rest of the country. For example, the ambitious Mars exploration mission of the Indian Space Research Organization, Mangalyan, is believed to have cost just one-tenth of similar missions by other countries. (*Krishnan RT, Prashantham S. Innovation in and from India: The who, where, what, and when. Global Strategy Journal. 2018;1–21. https://doi.org/10.1002/gsj.1207).* Frugal innovation is not just a need of emerging economies, this trend has gained momentum and acceptance even in mature markets, as it leads to resource efficient production and fine focus on the customer requirements such as functionality and cost advantages.

2.1 The historical perspective and how the Indian ecosystem developed:

In the early 1950's India chose to structure its Science Programme on the lines of the Russian model of strong fundamental research. Many decision makers within the S&T scenario still believe that fundamental research and applied research are inter-dependent, and can be pursued equally by the same institution. However, Indian Industry which was initially protected from global competition, and subsequently aligned itself to globalisation only in the early 1990s, always had the advantage of a big domestic market and few large players, and hence did not experience the imperative of innovation to tackle competition. Therefore, Industry did not pursue the path of innovation for differentiation, and also did not invest in medium or long term R&D. Instead, it preferred the short-term approach f in-licensing and quick financial results. The structural disconnect of an industry that seeks quick results and research institutes that invest in fundamental research manifested itself in poor relations between the two stakeholders.

Over a few decades, the divide between Industry and Academia had widened and resulted in a lack of communication between the two, which is manifested as a lack of trust, and a mismatch in expectations from each other. The spin off effects are, that product innovation in India is a rarity, and so is the necessary infrastructure such as manufacturing or testing facilities (at industrial scale) within the research institutions. Additionally, regulations such as out-dated Labour laws (recently amended) and regulatory policies made it unattractive for companies to increase their scale or invest in R&D; instead they rather focus on remaining small so that they could benefit from the subsidies and grants from the Government. This has resulted in lack of scale and size of the industry, with just one or two large companies in critical sectors such as machine tools and automation, or precision manufacturing industry with the rest remaining cottage or small and medium sized. However, very concrete steps are being taken by the Government of India now to bring the stakeholders closer and enable a symbiotic relationship between Industry and Academia.

The innovation culture of the Indian industry is at a nascent stage, particularly due to the fact that family-owned and led enterprises largely refrain from ploughing back profits into the R&D for the company. The Automotive industry is a case in point where despite the influx of foreign technology when the Indian Industry opened its doors to globalisation, the focus has been on in-licensing and "Art-to-Part" rather than embracing Product Innovation. In recent times, there is a larger appetite for innovation, with Tata Nano being a shining example. On the other hand, the Pharma Industry, India's most R&D-intensive industry, largely led by technocrats, has been a game changer where innovation has been the hallmark of this industry. NSTMIS, 2013). The IT sector remained largely at the level of IT back-end support rather than ushering in transformational R&D in user domains. This is now changing rapidly with Engineering and Design services growing at a rapid pace.

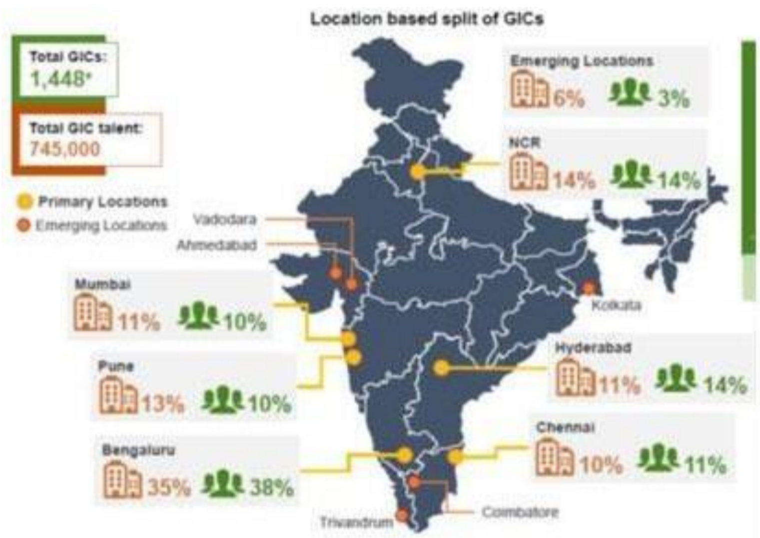
2.2 The imperative that drives the urgent need to develop appropriate innovation ecosystems

India missed the economic revolution in the 60's during which most of the East Asian countries such as Taiwan and Singapore marched ahead. With the globalisation in 1991, India has heralded its advent into the emerging economies of the world, and has since grown substantially in terms of GDP. In the period following the economic liberalization of the early 1990s, the country has seen the rise of the Indian software services industry (Arora, Arunachalam, Asundi, & Fernandes, 2001; Krishnan & Vallabhaneni, 2010; Pant & Ramachandran, 2012), the internationalization of the pharmaceutical industry, particularly in generic drugs (Chittoor & Ray, 2007), instances of catch-up in the auto components industry (Kumaraswamy et al., 2012), which include outward-oriented innovation, and frugal innovations such as the development of the low-cost Tata Nano car in the automotive industry (Radjou et al., 2012). The ambitious target of becoming a 5 trillion $ economy however can only be achieved if India is able to accelerate the trajectory of advanced manufacturing and innovation.

With several hundreds of the top MNCs having their captive R&D Centers in India, with its extremely qualified young workforce and a large domestic market, India has some of the key prerequisites of being a global innovation hub. Over time, many of these centres have grown in size, and they account for a nontrivial fraction of the overall R&D strength of their parent companies. The scope of these centres has also increased. Some of them have taken on global product responsibilities or at least responsibility for some significant module.

An emerging role for the Indian R&D centres of MNEs is taking the lead in developing products that can meet the needs of India and other emerging markets. For example, Jha, Parulkar, Krishnan, and Dhanaraj (2016) document how Cisco developed a range of cell site routers to meet the needs of Indian mobile service providers to straddle old (2G) and new (4G, MPLS) technology simultaneously in their mobile service networks. These products operate in the so-called last mile of the telecommunication network and constitute the entry point for consumer voice and data. These products were entirely conceptualized and ultimately developed by Cisco's R&D center in India in response to a perceived opportunity to serve unique emerging market needs. The product incorporated the latest features, but its development followed a frugal approach. Eventually, Cisco also sold the product in its developed markets as well, thus representing an interesting example of the much sought after but difficult to accomplish phenomenon of reverse innovation (Govindarajan & Ramamurti, 2011). Mudambi et al. (2017) highlight Renault-Nissan's Kwid project as one of the most ambitious examples of a multinational using India for innovation. Other companies like Renault and Gillette have embraced frugal innovation approaches to develop products especially for India and emerging markets (Krishnan, 2013c). These examples underline India's potential to do effective innovation across the value chain if structural impediments are removed.

TABLE 1: Multinational R&D Centers in India



Source: www.nasscom.in, GICs in India, emerging centres of excellence

As part of its Growth Story India seeks to fast track a transition from measured growth and limited connectivity to hyper-growth, resulting in leapfrogging of technology, as an alternative to the slow and steady evolution that industrialised nations experienced. However, as explained earlier, the infrastructure and the ecosystem of industry and academia collaboration is not yet fully in place.

On the other hand, Start-ups in India are emerging at an impressive speed, and young people prefer to go through the route of entrepreneurship rather than employment.

We believe that the system that is likely to work in a country like India, is one of a multi-stakeholder ecosystem of innovation hubs with start-ups, academia and industry that will incubate, demonstrate and leapfrog technology interventions. Independent companies will pickup proven technologies from these hubs and scale them in a shorter time cycle to the market.Indian Industry has, in general, not demonstrated the temper and culture to invest in medium to long term R&D. The focus is more on in-licensing or short term IPR that can be quickly exploited to get profits. This is also due to the nature of a large growing economy which faces disruptions and dramatic developments in many of the growth areas as against mature economies that offer a relatively steady environment.

Reflecting the cultural mindset elucidated above, the total contribution of R&D is a mere 0.8 % of the GDP, largely driven by Government investments and allocations, of which the private industry's contribution is approximately 0.3%. In a bid to accelerate the R&D growth to at least 2.0 % of GDP, the Government of India has initiated several programmes and funding instruments to foster innovation. These include setting up of centres of excellence in various locations with specific industry focus, and providing funding mechanisms for 80% of project cost (example SAMARTH Initiative by DHI). Sectoral initiatives to support Biotechnology and Medical devices are also noteworthy.

The programmes such as Skill India and Digital India seek to empower the young workforce of India. It is recognised that manufacturing needs to be a major engine of growth in India and the Government seeks to enhance its contribution to GDP from the current 16% to 25%. Towards this end, the Government has initiated the Make in India programme, that seeks to attract large MNCs to set up their manufacturing operations in India, using the local supply chain to leverage the cost arbitrage. However, the results have not been as expected, perhaps due to the poor innovation and quality focus of the Tier 2 and 3 companies. The Government has recently announced a programme to attract investments in 10 priority sectors using Production-Linked incentives – the objective is to get some of the largest players in these sectors to establish supply chains at a much larger scale than before.

2.3 How to strengthen the Indian Innovation Ecosystem:

While the Indian innovation ecosystem has some strengths noted above, there are many dimensions on which further development is needed in order to create a contemporary and dynamic ecosystem which delivers economic impact to the country:

- **Policy Initiatives:** One of the most important elements in efforts towards fostering R&D is the need for consistent and focussed funding programmes by Government which aligns its funding and grants programmes more closely and brings a synergy among its constituents. Large funding to exemplary academic institutions needs to be followed up to ascertain their efficacy and outcome. Different ministries that provide funding for similar outcomes should coordinate their efforts and align them to achieve greater synergies. Funding for private sector should be made more accessible. The Department of Biotechnology has an excellent programme to fast track innovations from Industry in Hi-risk areas (Birac), but most other Ministries still find it difficult to fund industry contributions. Several countries support a healthy partnership between the industry and research in project areas that do not easily attract investors. In such fields, industry is also funded so that they can bring in their knowledge and market understanding to accelerate the innovation curve and also on-board their commitment as users of the research results. The Public Sector companies which receive huge financial support from Government could be an excellent candidate to set up proof-of-concept for new ideas such as battery technologies, renewable energy projects etc., as they have excellent infrastructure, and can collaborate with research institutes to test the results of fundamental research. There is an urgent need for an overarching framework by the Government on R&D which should lay out the key areas of focus, identify strategic stakeholders, define innovative funding patterns and chart a clear roadmap for the desired outcomes so that all stakeholders including those from the Government are aware of the strategic thrust, are aligned to the common goals of the country and synergies among organisations can be developed.
- **Encourage collaborative research and multi-stakeholder partnerships:** Most outstanding institutions are working in silos. They do get intermittently involved in collaborative research with similar institutions or private industry. An incentive to collaborate should be introduced so that the knowledge gained does not remain restricted to these institutions but gets translated to the larger good of the economy or to the broader stakeholder base.
- **More focus on the RoI of funding programmes: Extreme dependence on a small group of brilliant academic institutions for applied research:** It is a global best practice that grants and largesse given to institutions are evaluated on criteria that justify the funds spent. The Government funding programmes should have a strong built in Monitoring & Evaluation (M&E) mechanism that evaluates inter alia if other partners were involved in projects, whether the outcomes of such projects have

reached the market or been picked up by industry for scaling, whether MSMEs have benefitted, and how many spin offs have been created.

- **Remove Structural gaps in incentivising collaboration among institutions:** Innovation presupposes cross fertilisation of ideas. By encouraging and indeed mandating institutions to collaborate, knowledge is shared and thereby capabilities are developed at a broader level. The Research and Innovation Landscape in India should create a structure aimed at developing synergies among institutions and work towards a common cause, leverage strengths and converge on strategic focus areas of the country. UK Research Innovation is the umbrella organisation for Research, Innovation and Industrial incubators such as catapult. Fraunhofer in Germany is embedded in the University landscape with every Head of Fraunhofer Institute being a Chair of that discipline at the University and hence the institutional links are established. There are programmes that encourage and facilitate cooperation between Max Planck, Fraunhofer, Helmholtz and other scientific partners.
- **Improve Infrastructure** for common use and sharing of resources (Labs/testing equipment and machinery). Industry does not find any value in working with institutions that are far behind in terms of content and infrastructure. If the manufacturing and testing infrastructure in the research institutions is ahead of the industry by at least a couple of years, this will be a formidable reason for industry to work with the research institutions in a more intense manner.
- **Open Innovative culture** in research institutions is imperative to encourage innovation. Incentives for Spin offs by researchers, structural initiatives to engage with Industry need to be set in place. Professors from the academic institutions are primarily evaluated on the basis of research papers, not entrepreneurship, although the trend is changing. Spin offs by scientists and Professors should be encouraged and leveraged for scaling by Industry.
- **Systemic mentoring and progression for young talent**: Most young postgraduates interested in research relocate to the US or Europe to pursue PhD Programmes. In order to increase the number of PhD students in India, concrete step have to be taken. Companies like Microsoft are already working on increasing the number of PhD students they support, and similar programmes need to be facilitated. Young student researchers are a great resource who not only question status quo but also are a much cheaper than full professors on a research project. Fraunhofer for example has 30% of its overall employee base formed by Doc and Post Doc students. The trend of top engineering institutions like the IITs shifting emphasis of their academic programmes to Masters and Doctoral levels should be intensified and supported with adequate resources.
- **PSUs involvement in R&D for strategic topics with institutions**: PSUs get strategic projects and high level funding from Government. They also operate for the larger public good and have a much larger canvas to play on. They should be encouraged to work closely with Indian research institutions to develop proof of concept and

breakthrough research. They can be a powerful intermediary to test at pilot scale and thereby facilitate large scale adoption and deployment by private industry.

- **Government funding should support not only R&D institutions but also industry in hi-risk projects and topics**: The funding programmes of most countries in new areas of research and high risk projects foresee funding for all partners be it industry or research institutions. In India however, Industry partners do not get funding (except for a few cases like DBT) but merely funding based on low interest which needs to be paid back once the research result is ready. This is unattractive for industry partners, and also does not underscore applied market driven research. Industry should be seen as a valuable partner from the very first stage, and a call for proposals that ensures a robust and transparent selection process can be used to avoid any malpractices.
- **Competitive, seed Funding: Assured** 100% funding by the Government results in research institutions not being sustainable, and not accountable for their operative costs or funding of projects through third parties. Institutions should be encouraged to be partners "with skin in the game", whereby they contribute through income from third parties. Even if funding is provided up to 100% in the first year, there should be a model of reducing contribution by the Government over subsequent years, leading to at least 50% funds coming from third party projects. As can be seen from the example of US and Europe, applied research institutions are quasi government, autonomous organisations, that earn a large part of their budget through industry- driven projects as well as from other sources.
- **Technology capability was largely built in large companies** and concentrated in a small niche group thereby depriving the MSMEs of the benefits of innovation. This has led to a low common denominator of technology readiness across the breadth of the industry. In other countries, MSME is the engine of innovation. The evolution of the Indian Industry is heavily skewed with some companies being almost world class and a large segment remaining deprived of basic technology, thus creating islands of excellence. In the country's interest, there should be research and development on basic technology applications for a larger base of industries including SMEs so that the supply chain is strengthened and the level of technology capability in the country is maintained at healthy levels. Towards this, the government should consider multiple pre-competitive projects and training/shared equipment for the MSMEs to raise their innovation and technology capabilities. The MSME Tool Rooms (Technology Centres) can be used very effectively for helping the MSMEs achieve the state-of art technology in their respective sectors.
- **Innovation Culture**: Indian Industry largely prefers in-licensing and buy back arrangements, rather than investing in medium to long term research. While this is the most difficult issue to resolve as it takes a long time to develop the requisite culture, steps need to be taken to encourage industry to invest more in R&D. The recent decision to allow the 2% of the company' earnings as CSR contribution for R&D projects is a very welcome move.

- **Cluster initiatives in India are largely real estate options:** Most of the clusters (SEZs/STPIs) established in India are largely real estate ventures, as they accommodate any stakeholder who wishes to set up operations in the area allocated. There are no cluster managers who work on behalf of the cluster, there is hardly any collaboration or cooperation among the cluster companies, nor is there a common research centre with training and testing facilities. There is hardly any evaluation of the clusters to understand the outcome of these cluster initiatives. In contrast, clusters abroad are a strategic initiative, involving selection of the resident companies, ensuring the participation of the entire value chain starting from raw materials providers to users, are led by a cluster manager who manages and markets the cluster, includes a centre for training, research and testing as a shared resource for all participants, and presupposes collaboration with the universities and centre of excellence as well as an M&E system that seeks to ascertain and validate the acceleration of innovation that such clusters are deemed to achieve.

3.0 RECOMMENDATIONS FOR POSSIBLE MODELS AND INITIATIVES

In order to accelerate innovation and market-driven research in India, the most important step would be to "open up" the ecosystem. In order to stimulate a multi-stakeholder engagement and participation, it would pertinent to set up at least 3- 4 innovation clusters that break the "business as usual" syndrome and drive home the urgency and need to focus on value driven research.

- The clusters (ASTRAs- **A**pplied **S**cience and **T**echnology **R**esearch **A**lliances) should be multidisciplinary in their pursuit of innovation yet focussed on a specific thematic area, include all stakeholders within this field and be led by a Cluster Manager who is a Technology Manager (not scientist). The Clusters could be in the following areas:
  - Smart Manufacturing and materials (Digital Manufacturing, Industry 4.0)
  - Smart Energy (Solar, Wind, Thermal, Hybrid, Grid Integration, E-mobility)
  - Artificial Intelligence (Health, Agriculture, Manufacturing)
  - Defence and Aerospace
  - Health, Pharma and Medical Technologies
  - Smart Mobility (multimodal transportation, new generation mobility, E-mobility)
- Each cluster will be funded by the Government and by the other stakeholders including industry (60:40 or 70:30). The clusters will be incentivised for collaborative research (participating in calls jointly with other partners).
- The Clusters should be autonomous and self- sufficient for their operating costs.
- Each cluster will be led by a cluster manager (CEO) who is a Technology Manager (not a Scientist) with marketing and communications skills accompanied by a good understanding of the thematic area of the subject. He/She should be hired from the free market, and not deputed from any of the scientific institutions.

- The cluster should possess infrastructure such as machinery, equipment and testing facilities that are at least 3- 4 years ahead of industry state of art. This will render it attractive for industry to come to the cluster for shared resources as well as contracting the institutions for research projects.
- The Funding for the clusters should be highly innovative and out of the box, ensuring financial participation by all stakeholders (ownership and good returns on the investment. The Government could initially fund 100% of the costs, and over a 5- year period reduce its contribution on a yearly basis, with industry and other stakeholders increasing their contribution. This will provide for a proof of concept as well as advocacy for the industry to participate with more energy and vigour. All clusters should have a business model that works towards generating at least 50% of its funds and their continued support should be evaluated on the ability of fulfilling this criterion.
- The projects financed by the Government should be based on a call for proposals that mandates institutions to work on a collaborative approach. Large scale funding of single institutions should be avoided.
- Applied research institutions such as C-DAC, IIITs, and Technology Centres (Tool rooms) as well as some excellent CSIR Labs should be utilised as accelerators as they are closely connected to the industry and have extremely qualified sector experts. They should be charged to take the fundamental research work from the academic centres of excellence such as IITs and IISc to the next level of Technology Readiness (TRL- 6-9).
- Culture within the research institutions should encourage young researchers and have strategic initiatives that empower young researchers to stay within the system for PhD and post doc work. This young research cohort is an excellent resource for questioning the status quo and also make the research projects extremely viable and cost competitive.
- It would be useful for each cluster to develop an international alliance partner. This would facilitate access to international collaboration opportunities, mobility of researchers, and knowledge sharing among peers.
- Monitoring and evaluation at defined regular intervals is extremely critical to establish the efficacy of these clusters and make them sustainable. Defined parameters such as number of industry projects, collaborations with peers, international linkages, mentoring of Students, spin offs created, MSME participation etc. should be drawn up to evaluate the efficacy and acceptance of the Cluster.
- IIT Madras Research Park has shown the potential of structured initiatives to encourage collaboration between high-end academic institutions, large corporate entities and start-ups to facilitate dynamic innovation outcomes. The IIT Madras Research Scheme concept measures and monitors interaction by the Research Park occupants with IIT Madras professors and students to ensure collaborative projects happen.

- The creation of similar research parks around established institutions and research laboratories with relevant collaboration metrics in place would be helpful. Educational institutions may be encouraged to formulate start-up policies that recognise participation of their faculty and students in start-ups as a desirable activity. This will help research ideas from the lab get commercialised more effectively.

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SMART WATER FUTURE INDIA

BACKGROUND:

Coimbatore faces rapid growth in the next decades, increasing the pressure on natural resources and the need to secure water, energy, and food supplies. As one of India's 100 Smart Cities, Coimbatore has embraced the chance to realize exemplary solutions and set the course for a sustainable urban development. The project "Smart Water Future India" (SWFI) is funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMU) under its Export Initiative "Environmental Technologies". The project SWFI aims to develop a smart, sustainable water management strategy for Coimbatore and establish a Water Innovation Hub for long-term cooperation between local stakeholders and German institutes and companies.

Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB) is the lead coordinator of this project. Dr. Marius Mohr, Head of Innovation Field Water Technologies and Resource Recovery from Fraunhofer IGB is the Head of this project. Other partners of this project are Drees & Sommer, Institute for Social-Ecological Research (ISOE) and trAIDe. The partners involved in the project SWFI are experienced in the development of strategies and solutions in the field of integrated water management world-wide, including the topics water supply, wastewater disposal, and storm-water management. The project was facilitated by Coimbatore City Municipal Corporation (CCMC) and Noyyal Life Centre in Coimbatore.

APPROACH:

The methodology for the analysis of the urban dynamics and strategy development is based on the "City Lab" approach developed inside Fraunhofer research network "Cities of the Future".

- Understand: Local expert interviews, analysis of water management status quo in Coimbatore.
- Involve: Discuss needs and potentials with local stakeholders and German water technology experts.
- Develop: Plan a strategy for integrated water management and incorporate feedback.
- Network: Develop the concept for a Water Innovation Hub for South India in Coimbatore.

The project team conducted multiple visits to sewage treatment and wastewater treatment plants, and met with important stakeholders of Coimbatore to understand and assess the impacts of energy, water treatment and waste management in the city of Coimbatore. This was followed by a large scale stakeholders' workshop that was organized in July 2018. Participants from Coimbatore Municipal Administration and other Urban Local Bodies, along with Private companies, Universities, and Civil societies in Coimbatore came together to discuss the topic of water management in the city. The objective of this workshop was to identify challenges, invite suggestions, ideas and partnerships for developing an Innovation Hub, which will formulate innovative, economic and sustainable strategies for developing water sector in Coimbatore, with a view to forge a long-term cooperation between local stakeholders and German institutes and companies.

RESULT:

This workshop deliberated upon the strategies for three major challenges in Coimbatore namely Semi-centralized sewage treatment, water quality data monitoring respectively and setting up of a Water Innovation Hub, which were discussed in the working group sessions of the workshop, and their respective results were presented to stakeholder and the city corporation.

1. **Semi-Centralized Integrated Water Management:** Semi-Centralized Water Management integrates different technologies, combining benefits of large, centralized infrastructures and smaller systems, also considering the energy and food sectors.

   Problems to be addressed:
   - Insufficient wastewater collection and treatment infrastructure.
   - Pollution of water bodies (lakes, River Noyyal, and groundwater).
   - Health problems, odour emissions, water scarcity.
   - Centralized concepts are not flexible and complicated to implement (obstruction of streets during construction etc.).
   - New facilities currently under construction, but still parts of the growing city without wastewater collection and treatment.
   - Municipal solid waste separation systems in is Coimbatore insufficient, leading to waste of organic resources.

2. **Water Quality Data and Monitoring:** Implementation of a smart monitoring and data management system for water quality and quantity. Technologies to monitor the quality of treated industrial effluents, surface waters and groundwater and to visualize the results.

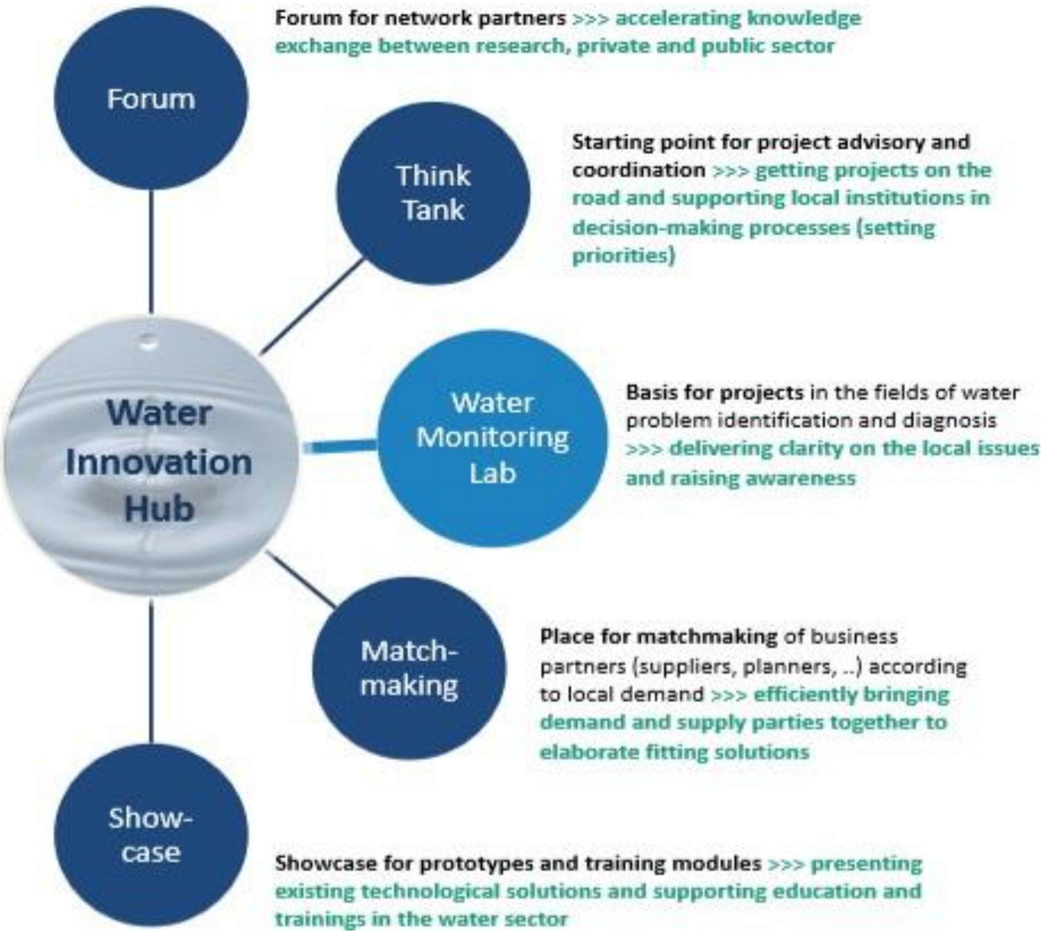
   Problems to be addressed:
   - Pollution of lakes, Noyyal river and groundwater is an urgent problem.
   - Human health is endangered by polluted water resources.
   - Data on water quality and quantity is important for identifying and locating of problems.
   - Monitoring is necessary as a basis for demonstrating the effectiveness of measures.

3. **Water Innovation Hub:** In the Water Innovation Hub, German and Indian companies work closely together with non-governmental organizations and city administrations to provide solutions for demand-oriented water management in India. Small and medium-sized German companies in particular can benefit from the network. The two identified fields of action provide first starting points for this long-term cooperation between Germany and India.

As a part of this project, a report on "Integrated analysis of water management and infrastructure in Coimbatore" was prepared and submitted in 2018. This report presents the current state of water supply and sanitation as well as the management of rainwater and other water sources in Coimbatore. As the water sector interacts with many other sectors and is an important component of urban development, other sectors like energy, waste, agriculture, industry, urban planning, governance, education are also addressed.

WATER INNOVATION HUB UNDER SWFI - CONCEPT

The Water Innovation Hub is the basis for a long-term Indo-German cooperation in the water sector.



OBJECTIVE:

Germany has decades of experiences in management and treatment of water and wastewater. Many German companies offer good solutions, and are exporting these solutions to other countries as well. India with its dynamic development has large demand in the water sector and is an interesting market for German companies. As most German companies are relatively small, they face difficulties on the Indian market, e.g. they do not have enough presence on site, are lacking relevant network partners, are not involved in planning water infrastructure, and might not always have solutions adapted to the Indian demand or the possibility to conceptualize and test prototypes. On the other side, Indian stakeholders are eager to exchange knowledge and technical solutions on the local water sector. Often the water situation on site is complicated and needs partners, who are willing and have relevant resources to develop, test and train solutions. **One of the results of the project "Smart Water Future India" is that there is a demand for a "Water Innovation Hub" acting as a platform in Indian cities in order to address the above-mentioned issues.**

A range of tasks for the Water Innovation Hub can be found in the figure below:

Diagnosis	Data monitoring	Data interpretation	Problem identification	Situation assessment
Consulting / advisory	Solution draft/ feasibility	Advice on strategic and operational level	Platform for prototyping/ showcases	Adaptation of prototypes for Indian conditions
Access to partners	To match companies	Access public funding	To enable knowledge/ tech transfers	To organize trainings

SETTING UP THE WATER INNOVATION HUB:

As the Water Innovation Hub should be addressing local issues, such a Hub will cover a city and its surroundings (e.g. in a radius of 50-100 km). As a minimum, two persons skilled in the local language will be in charge of the Hub:

- A coordinator, who is fluent in English, communicates over all usual means, is responsible for the communication and coordination with all partners.
- A senior advisor, who ideally has experience with the local administration, is responsible for the coordination with the different bodies of the local administration.

The staff of the Water Innovation Hub will be employed by an Indian organization, but independent from the local administration.

In the initial phase (2-3 years), the funding for these employees as well as for German institutions, organizing the set-up of the Water Innovation Hub should come from public German sources, e.g. the "Export Initiative for Green Technologies". In this phase, a number of selected German companies initiate a start-up membership of the Hub. After the initial phase, the member companies cover the costs for the Hub via a yearly fee. As first members, workshop participants of Smart Water Future India as well as members of the Regional Forum India of the German Water Partnership will be invited. At the same time, the Hub is open for Indian companies as well, as long as they pay a membership fee. Local companies from the water sector will be addressed explicitly.

To be able to test the concept of the Water Innovation Hub under different conditions, **two Hubs will be started in parallel: one in Coimbatore (Tamil Nadu), where the concept has already been introduced by the Smart Water Future India project, and one in Solapur (Maharashtra), where the state of Baden-Württemberg initiated a partnership.**

IMPLEMENTATION:

First, the Water Innovation Hub serves as an office where information converges. A database on the water infrastructure in the city is created, which can be successively expanded. The exchange of students is organized. A homepage is set up, every two months a newsletter is published and sent to the members (content: current developments in the water sector of the city, new tenders etc.). Frequent social media posts (e.g. LinkedIn) will bring the Hub digitally to life. At the same time, the

Water Innovation Hub will be noticed (press reports etc.).

POTENTIAL PILOT PROJECT *(Eg: Water Quality Data and Monitoring System):*

The monitoring of surface waters shall be established as a system solution/product in the context of the Water Innovation Hub. An exemplary implementation will take place at one of the lakes in Coimbatore. Interested companies will be involved via the Water Innovation Hub. This will give the Water Innovation Hub greater momentum and at the same time increase the chances in successfully implementing the monitoring system solution in Coimbatore. The aim is to create a data set by means of monitoring that can be used to demonstrate the added value of this system solution. Accordingly, a business model is to be developed which enables the participating companies to market this system solution.

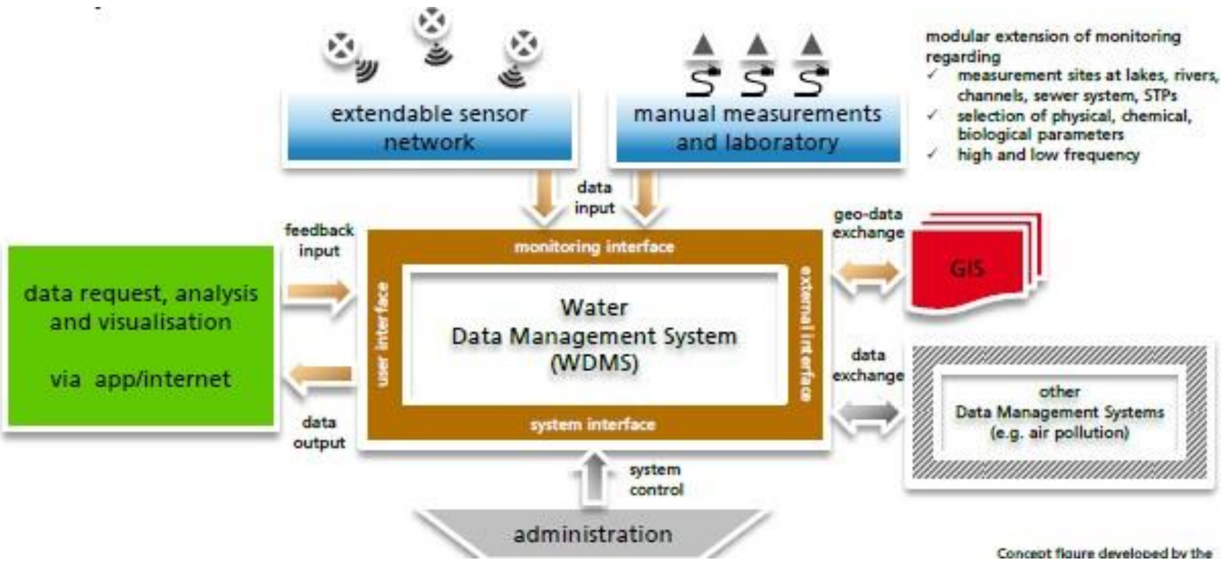
SCALABILITY:

Since the Water Innovation Hub focuses on solving local issues, but refers to similar circumstances in other Indian cities or even fast growing cities around the globe, the concept and its outcomes will be easy to multiply once tested.

PRESENT STATUS AND WAY FORWARD:

The implementation of the Water Innovation Hub strategy is currently being prepared. The German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMU) has awarded Fraunhofer IGB and its interdisciplinary consortium with means to pursue the realization of initial Water Innovation Hubs in Coimbatore and Solapur. '*AQUA-HUB - SMART Water Quality Monitoring & Water Innovation Hubs for fostered Indo-German collaboration'* addresses the needs of the local water sectors identified in previous projects, as well as the challenges of the German water industry to develop projects, relationships and business on the Indian market. A local presence is of great importance for the relations and the accelerated exchange of information between the German and Indian actors. Therefore, local Hub Managers will be regularly mediate knowledge transfer via digital communication tools and frequent exchanges. In addition to network activities and the mediation of business partners, the hubs fulfil the function of project centres for the realisation of technical demonstration projects and increase the exposure with environmental technologies "Made in Germany". These demonstrations are needs formulated by the local actors and are supported by the German water industries. The envisaged piloting of German water monitoring technologies thus offers the opportunity to meet these needs with manageable investments and risks and to create the basis for both better data availability on site as a starting point for measures to meet environmental goals and subsequent technology transfer. In Coimbatore, a reference for online water quality monitoring at the local network of lakes will be established. Sustainable rejuvenation of the lake water and development of the lake area is of high interest to the city. Increased data availability can complement the identification of measures and support the Smart City approach in Coimbatore. In Solapur the Water Innovation Hub will link with the Project of 'Smart Water Quality Monitoring in Solapur' funded by the state of Baden-Württemberg. Flow measuring devises and water quality monitoring sensors will be implemented at a Water Treatment Plant in Solapur in order to support the Smart City Strategy in Solapur and facilitate the operation and monitoring of processes at the plant via a data-driven digital tools.

Ongoing further development of the Water Innovation Hubs is advised by an advisory board. Additional services of the hubs will be developed in order to create a sustainable, financially viable and transferable format. At the same time, the technological adaptation requirements of the German measurement technology will be determined. As network and project centres, Water Innovation Hubs in the cities of Coimbatore and Solapur contribute to sustainable development & the consolidation of Indo-German cooperation in the water sector while demonstrating the potential of technology transfer using Smart Water Monitoring as an example.

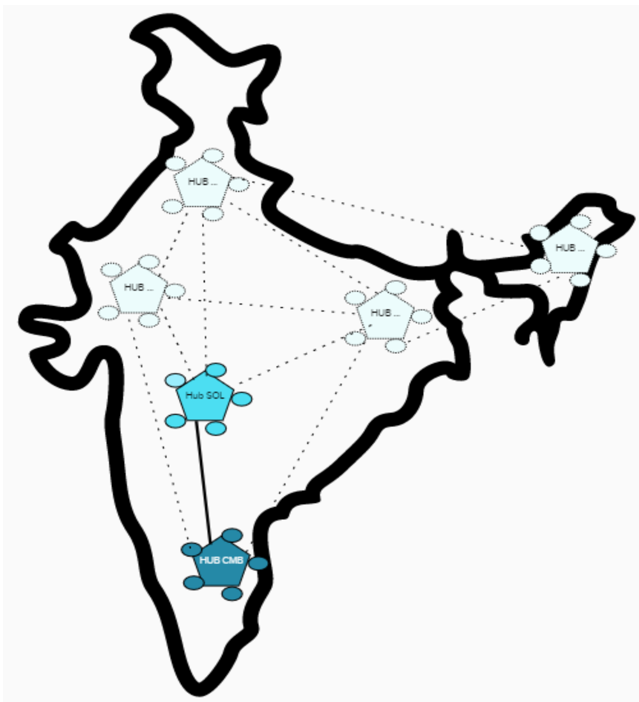


Concept of a smart water data management system

INVOLVED INDIAN PARTNERS (PRESENT STATUS):

- CSIR - National Environmental Engineering Research Institute (NEERI)
- Consortium for DEWATS Dissemination Society (CDD Society)
- Noyyal Life Centre (Siruthuli)
- Let's Bridge IT

VISION OF THE DEVELOPMENT OF INNOVATION HUB NETWORKS ACROSS INDIA



ISSN 1980-5411 (On-line version)
Production, 30, e20190151, 2020
DOI: 10.1590/0103-6513.20190151

Thematic Section - Present and Future of Production Engineering

Building up a national network of applied R&D institutes in an emerging innovation system

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Abstract

Paper aims: This paper aims at answering the research question "How to successfully build up and strategically manage a new network of applied R&D in Brazil?"

Originality: The paper is based on a unique experience of a strategic partnership, transferring the experiences of managing the largest network of applied research in Europe to the Brazilian National Innovation System (NIS).

Research method: The research described in this paper follows an action research approach, using a participative process of rapid prototyping, pilot tests and continuous revision and adaptation.

Main findings: The paper presents a comprehensive and consistent set of management models, procedures and tools for the planning, implementation and evaluation of applied R&D institutes.

Implications for theory and practice: The paper's findings contribute to the empirical research on methodologies to manage knowledge-based networks and innovation actors at the interface between research and industry.

Keywords
Applied research. National innovation system. Brazil. Network governance. Business planning. Strategic Management. Evaluation.

How to cite this article: Kohl, H., Will, M., Prim, M.F., Pavim, A. X. (2020). Building up a national network of applied R&D institutes in an emerging innovation system. *Production, 30*, e20190151. https://doi.org/10.1590/0103-6513.20190151

Received: Dec. 2, 2019; Accepted: Feb. 2, 2020.

1. Introduction

With a GDP of 2.138 billion USD (2018), Brazil is the ninth largest economy of the world. SENAI is the National Service for Industrial Apprenticeship and belongs to the National Confederation of the Industry (CNI) in Brazil. Its main mission is to provide technical education to qualify the industrial workforce of Brazilian companies. Despite previous experiences in providing technological services, such as metrology and technical consulting, the business area of applied research, technological development and innovation (RDI) was almost entirely new to the organization with approximately 20,000 staff in various operational units distributed over whole

Brazil.

Fraunhofer Gesellschaft is the largest organization for applied research in Europe with over 27,000 staff in more than 75 institutes distributed over Germany, and with various international partnerships and subsidiaries. The Berlin-based Fraunhofer Institute for Production Systems and Design Technology (IPK) has vast experiences in international consulting regarding the development of regional and national innovation systems. IPK's division Corporate Management is specialized in developing and implementing management systems for companies, public clients and research institutes. Based on these experiences, SENAI assigned Fraunhofer IPK with supporting the establishment of the new national network of applied R&D institutes in Brazil.

In 2012, when the project to build up the network of 25 SENAI Innovation Institutes was started, Brazil was ranking on the 58th position of the Global Innovation Index (Mobilização Empresarial pela Inovação, 2018a) and the economic scenario in the country was characterized by concluding a decade of strong economic growth, which was partly based on the increasing exports of raw material and commodities, such as meat, coffee, soy and oil, among others. The other part of the economic growth was mainly triggered by internal social programs which increased the buying power of the Brazilian population significantly, and thus, strengthened the domestic market for consumer goods on a broad basis, taking the population of approx. 200 million inhabitants and Brazil's continental size into account.

Already foreseeing at that time, that this economic scenario would not serve for sustainable economic growth and future increase of national wealth in the long run, the leading industrial players and large Brazilian companies articulated the need for a shift towards higher added value in the national production chains, including the increase of productivity and added value through technology and innovation. This led the Entrepreneurial Movement for Innovation (MEI), consisting of the CEOs of the largest industrial companies in Brazil (Mobilização Empresarial pela Inovação, 2018b), to request a national initiative with the aim to support the Brazilian industry in tackling this challenge of introducing technology and innovation to the companies as a means to strengthen the competitiveness of the Brazilian industry in a globalized economy.

Seven years later, after a severe economic crisis and dramatic political turbulences, and Brazil ranking on the 64th position of the Global Innovation Index (Mobilização Empresarial pela Inovação, 2018a), this need becomes ever more evident. Recent developments, like the creation of a national funding program for industrial research and innovation (EMBRAPII), the free trade agreement between MERCOSUR and the European Union as well as attempts to reduce bureaucracy and the protection of the domestic market, have pointed into a favorable direction. At the same time, the constraints and barriers for industry-financed R&D remain high in the current Brazilian economic scenario with a history and business culture not yet acquainted with investments in technological innovation on a large scale. Breaking up these barriers at least partly and demonstrating the economic benefits and return of investment of industrial R&D, is thus, one of the market challenges this new applied R&D network has to face.

2. Background and methodology

Innovation is the driving factor for economic development, growth and the wealth of nations (Schumpeter, 1912) and is widely understood as a complex process (Drucker, 1985) involving different types of actors from the public and private sector (Mowery & Rosenberg, 1993; Chesbrough, 2003; Hauschildt et al., 2016), often organized in networks (Kozioł-Nadolna & Świadek, 2010; Barbieri & Álvares 2016; Taferner, 2017). These actors from the different societal sub-systems together form the National Innovation System (NIS), a term first introduced by Freeman (1987) and defined as: "[...] the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies." (Freeman, 1987). Nowadays, these inter-organizational networks are viewed as a major driver of innovation (Ozman, 2009; Ringwelski, 2017), which has led to a sharp increase in research and publications on innovation networks in the last two decades (Battista Dagnino et al., 2015).

On the macro-level, successful innovation processes rely on the effective interplay between different organizations from science, industry and government which is usually referred to as the "triple helix" concept (Leydesdorff & Etzkowitz 1995). Intermediaries are key to overcome structural challenges inside these innovation networks and are defined as hybrid organizations which operate at the interface between two or more sub-systems of the triple-helix model (Ranga & Etzkowitz 2013), e.g. technology transfer centers, venture capital firms, business angel networks or Research and Technology Organizations (RTOs). RTOs link research and private sector innovation with the task of transferring scientific results to the private sector (Organisation for Economic Co-operation and Development, 2011). Examples of RTOs are the Fraunhofer Society in Germany, TNO in the Netherlands, VTT in Finland, Tecnalia in Spain and SINTEC in Norway (Organisation for Economic Co-operation and Development, 2011).

The role and functions of RTOs in Innovation Systems has been investigated in comprehensive research (Organisation for Economic Co-operation and Development, 2002; Roll-Hansen, 2009; Müller-Prothmann & Dörr, 2014), including a recent benchmarking study by MIT with a focus on the financial model of RTOs worldwide, examining the distribution of public funds and private (industrial) revenue (Reynolds et al., 2019; Zylberberg, 2017), as this mix of income is viewed as one of the specific operational characteristics of RTOs. The European Association of Research and Technology Organisations (EARTO) defines the function of an RTO as an organization which predominantly offers R&D, technological and innovation services to enterprises, governments and other clients (European Research Advisory Board, 2005). The majority of the investigated RTOs focuses on applied research and experimental development rather than basic research (Zylberberg, 2017), as their mission to transfer technology to industry requires application-oriented research results.

In this context, the 25 SENAI Innovation Institutes, being the research object of the present article, shall be classified as RTOs as defined above. Taking into account the existing examples and experiences with national networks of RTOs, SENAI decided to define a transversal technology and research field as the scope of actuation for each Innovation Institute, to be distributed over Brazil. The technology and research fields were chosen based on the current and future demand for technological solutions to increase the competitiveness of the Brazilian industry and its main sectors. The geographical distribution of the 25 Innovation Institutes was based on multiple criteria, such as experiences with certain technologies in existing operational units of SENAI, the proximity to clusters of potential industrial clients in a certain federal state or geographical area, among further technical and political criteria to ensure support and commitment of the main stakeholders. Figure 1 shows the fields of actuation and the geographical distribution of the 25 SENAI Innovation Institutes:

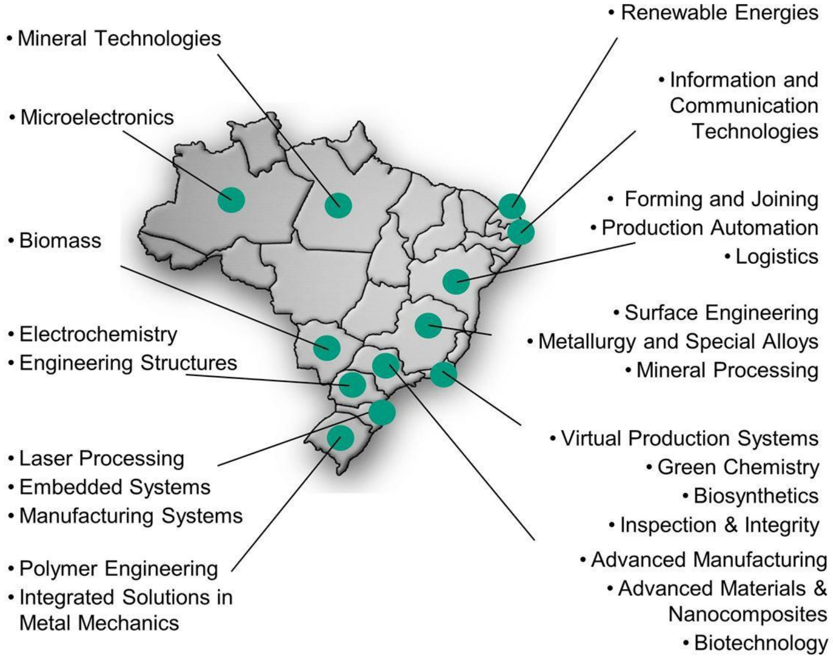

Figure 1. National Network of 25 Operational SENAI Innovation Institutes in Brazil.

Taking this pre-defined scope of the national RTO network as the initial situation, the present paper focuses on the practical implications of the ambitious endeavor to implement such a national network of Innovation Institutes from scratch and to direct it towards successful operations. Thus, the main research question of this analysis is defined as:

How to successfully build up and strategically manage a new network of applied R&D institutes with the aim to strengthen the industry's competitiveness in Brazil?

The management approach to solve this practical challenge had to cover two levels as a minimum prerequisite: On the network level overall strategies, objectives and guiding principles had to be defined and transferred into national standards for quality assurance and successful operations of all SENAI Innovation Institutes. On the micro- or actor-level, i.e. the level of the single institute, the main challenge was to develop and deploy adequate management models, methods, procedures and tools to support a systematic planning, implementation and continuous evaluation of each Innovation Institute in the light of the strategies and principles defined on the network level.

Effective and efficient network management requires actionable methods. Sydow (2010) points out that, despite the considerable variety of research on networks, much is still unknown about practical network management. Becker et al. (2011) agree that literature dealing with the phenomenon of networks under practical considerations is still scarce, underscoring the notion that the transfer of traditional management practices to the network context is at present inadequate. Despite the available practical experiences from existing RTO networks and their management systems, there are no widely accepted standards for comprehensive management systems and methodologies for RTOs. As many different types of operational models of RTOs exist in practice (Zylberberg, 2017), a standardization approach might also not be adequate. Therefore, general approaches and methods of strategic management as well as practical experiences with the management of international RTO networks were taken as a basis to develop a practical set of management methods and tools for the planning, implementation and evaluation of the SENAI Innovation Institutes, adapting the existing methods to the specific Brazilian requirements and environment.

Furthermore, the management methods and tools to be developed had to fulfill the specific requirements of an Innovation Institute: First, the nature of an RTO as a knowledge-intensive business needs to be taken into account, integrating the main assets of applied R&D actors into a comprehensive management model, i.e. the intangible resources and strategic success factors of each institute need to be displayed and turned into measurable, and thus, manageable objects (Will, 2012). Second, the two generic approaches of the innovation process need to be incorporated in an adequate management method for RTOs as an innovation intermediary between science and industry: the "market-pull" as well as the "technology-push" approach (Corsten et al., 2006; Müller-Prothmann & Dörr 2014). This corresponds to the third methodological requirement, reflecting a discussion with a long history in strategic management research: the management system needs to integrate the resource-based (Barney, 1991) and the market-based view (Porter, 1996) of the organization.

The deployed methodology to solve the research question stated above is following an action research approach from the point of view of the involved project managers of the two main organizations responsible for the development of an adequate management system for the network of Innovation Institutes in Brazil, SENAI and Fraunhofer IPK. Due to its characteristics, action research was chosen as the most suitable way to achieve a compromise between a structured research process and applicable results (Tripp, 2005). Because of these characteristics, action research can construct a suitable framework for the application of the developed method and its iterative improvement under genuine conditions (Coughlan & Coghlan, 2002; Mertler, 2017).

Following this basic action research approach, using existing standards in strategic management as well as practical experiences with managing existing national RTO networks as a first basis, prototypical models, methods and tools were developed in an agile manner, then tested in pilot applications and subsequently adapted and improved to serve the reality of the SENAI Innovation Institutes in their specific environment. In a participative approach these models, methods and tools were being reviewed according to the expected and produced outcomes by the user community in regular project meetings, i.e. by the directors and senior researchers of the Innovation Institutes on the actor-level as well as by the national department of SENAI as the central unit responsible for the coordination of the institutes on the network level. The results of these regular reviews were being integrated into the next cycle of development and improvement, and thus, leading to stable versions of management modules according to the specific needs of the institutes in each lifecycle phase. In synchrony with the process of growing and maturing the network of institutes, further modules with more elaborated features were developed and added to the final management system.

3. Shaping a network strategy for 25 applied R&D institutes

In the context described above, a national initiative for innovation was being designed, gathering major political supporters like the Ministries for Science and Technology (MCTIC) and for Industry and Foreign Trade Development (MDIC), including a strong engagement of the Brazilian Development Bank (BNDES). Triggered by the industry via MEI and other industrial channels, CNI took the lead in this initiative and assigned the challenging task to implement a national network of 25 “Innovation Institutes” to the national department of SENAI, integrating the Industry Federations in 13 states of Brazil and the respective regional departments of SENAI in these states as operational leaders for the actual physical and technological execution of this initiative.

In a first phase from 2012 to 2018, the 25 SENAI Innovation Institutes (ISIs) elaborated adequate business plans to subsequently steer the implementation of each institute in terms of scientific-technological infrastructure and qualified research team as well as to start the operations by executing first R&D projects for industrial clients. After this initial implementation and “ramp-up” phase had been concluded successfully with the 25 ISIs being operational, the focus of the responsible national department of SENAI and of the newly installed “ISI Network Governance Committee” shifted towards the strategic development and positioning of this new applied R&D network in the National Innovation System (NIS) of Brazil. Taking past experiences of the Fraunhofer

Gesellschaft in Germany and a recently developed typology of Research and Technology Organizations (RTOs) by MIT (Reynolds et al., 2019; Zylberberg, 2017) into consideration, the following model for the mid- to long-term development and strategic positioning of SENAI's innovation business was created (see Figure 2):

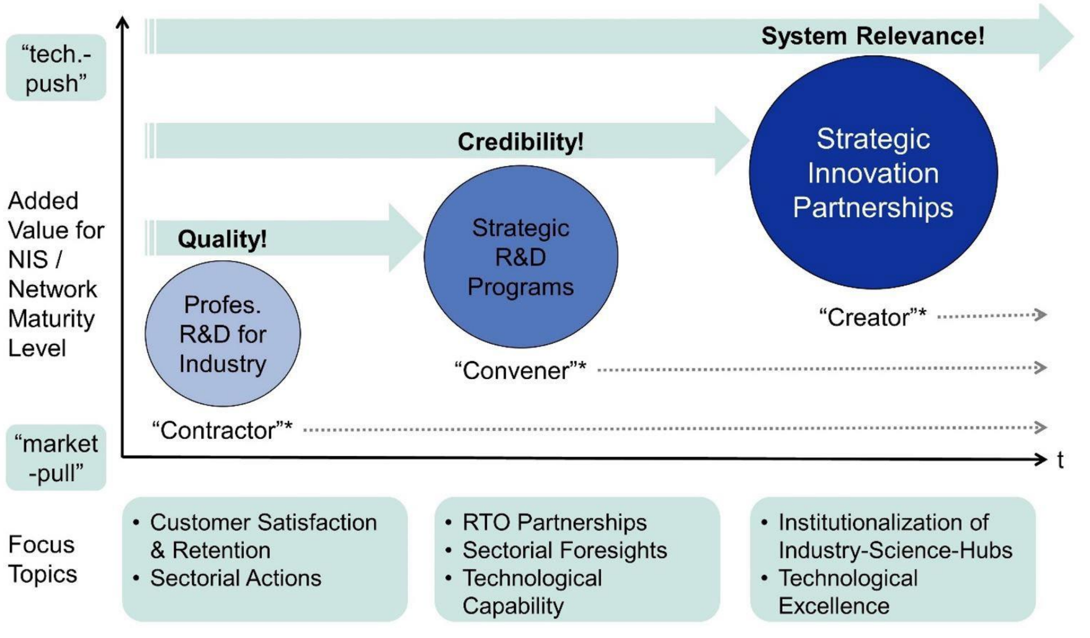

Figure 2. Strategic Positioning of SENAI's Innovation Network in National Innovation System (NIS).

In contrast to the usual development of public universities and research institutions towards becoming a professional applied R&D provider, which usually starts from the role "creator" (based on their public mission to create new knowledge and qualifying people), the SENAI Innovation Institutes did not start from this publicly funded scientific basis. With almost no scientific track record and no public basic funding for research, but being integral part of the industry federation, the strategy adopted by SENAI was to start positioning the ISIs behaving as "contractors", i.e. building up the capabilities and reputation to perform high quality contract research with a major part of the revenues coming directly from the industry. This strategy requires a clear demand-oriented market-pull approach with a focus on a professional industry-compatible culture of working and delivering the respective technological solutions.

Once having reached a certain maturity and reputation in delivering high quality research results with immediate practical benefit to the industry, a possible and natural next strategic stage to be conquered by the ISI network is the "convener" role, i.e. striving for and practicing the behavior of a "hub" or "netweaver" which attracts and integrates various different players from the research and the industrial world to format and steer larger and more strategic R&D programs, such as project consortia or innovation clusters with a long-term and/or disruptive research agenda, including different R&D partners and industry associations, e.g. focusing on the technological transformation of a whole industrial sector.

Once the position on the national market as a trustful and professional R&D hub is reached, a major next strategic stage focuses on the systemic layer of the national innovation system, using the strong reputation of the ISI network to influence innovation-related policies on the national level, i.e. becoming system-relevant for the NIS and thus, supporting to shape the national long-term R&D strategies as an important intermediary within the "triple-helix" approach, aligning the macro research agenda with the industry's agenda and the federal government to define synergetic industrial and research policies. Eventually, this strategy should also lead to sustain a more comprehensive "creator" role, also including a joint basic research and "technology push" agenda with partner universities and research centers, necessary for certain industrial innovation results in the long-term and the respective formation of new professionals in emerging fields of technology.

4. Strategic network governance and lifecycle management

In order to operationalize this strategy, a national network governance structure and a respective lifecycle management for the 25 SENAI Innovation Institutes had to be defined and implemented. On a macro-level this process of governing this R&D network was defined as follows (see Figure 3):

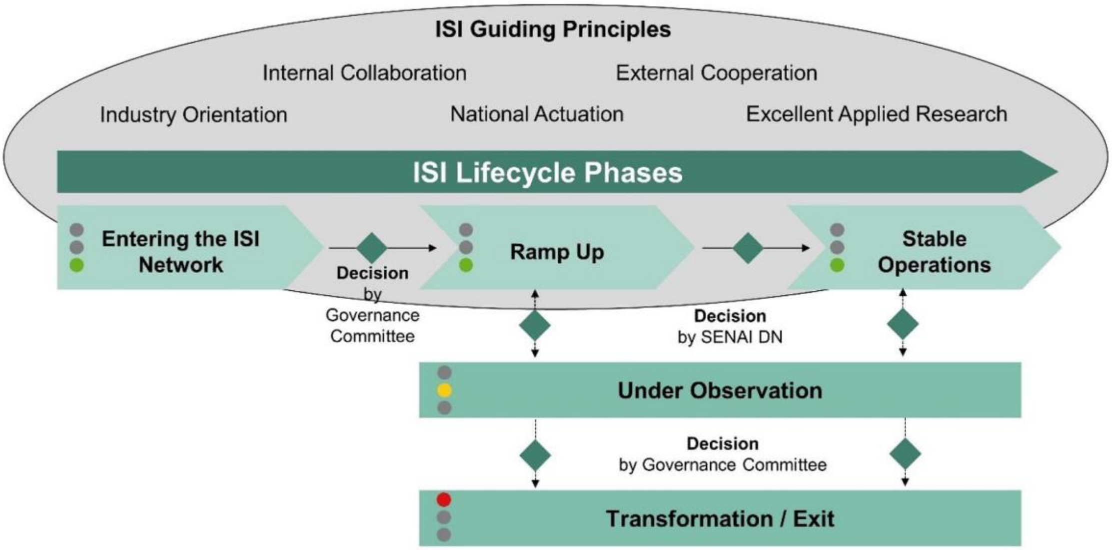

Figure 3. ISI Lifecycle Management as the Core ISI Network Governance.

The "Guiding Principles" were derived from the normative requirements of the main stakeholders and served as the starting point for elaborating the strategies and objectives to be operationalized and supported by the network lifecycle management:

- *Industry Orientation:* Each ISI shall predominantly work for the benefit of the industry, providing innovative technological solutions to increase the competitiveness of the industry in Brazil.

- *National Actuation:* Different from all other units inside the federative organization of SENAI, each ISI shall operate on a national level, offering and providing solutions in a nationally agreed transversal research or technology field.

- *Excellent Applied Research:* Each ISI shall strive for excellence in applied research and technological development, delivering innovative solutions with clear benefits to the industry and society in Brazil, performing on a state-of-the-art level of R&D.

- *Internal Collaboration:* Conceptualized as a synergetic network from the beginning, each element of the network (the ISI) shall seek collaboration on a resource, market and technology level with its counterparts in the network, creating a strong network value proposition together on the market, respecting the boundaries of its own research and technology area as defined in the network's national R&D portfolio to avoid significant technological overlaps and resulting competition inside the ISI network.

- *External Cooperation:* Following the concept of applied research, each ISI shall act as an intermediary player between basic research and industrial application, and thus, seek strategic cooperation with external R&D partners (e.g. universities, national and international R&D institutes), creating win-win-situations based on a complementary profile of actuation.

Further basic requirements of the main stakeholder and mother-organization SENAI included the following business objectives:

- *Financial self-sustainability:* Each ISI shall be able to cover its own operational costs by its own revenues by the end of the ramp-up phase, but at latest in the 8th year of operation.
- *Focus on applied R&D and innovation:* Due to parallel structures at SENAI dedicated to basic or off-the-shelf technological services (e.g. metrology and consulting on mature technologies), the so-called SENAI Technology Institutes (IST), it is important to ensure that each ISI focuses on its main business purpose "innovation", i.e. developing new technological solutions applicable in the Brazilian industry, mainly operating in R&D projects, rather than selling and applying ready-made technological services.

Taking these guiding principles and stakeholder requirements as the initial point of departure to design an adequate management system in order to support effective network governance, three main phases of the lifecycle of a typical SENAI Innovation Institute were defined. Each lifecycle phase displays a particular stage of maturity in the evolution of each institute. Considering that a) most of the first 25 institutes were built up from scratch, b) most of the involved regional departments of SENAI had little to no experience with professional research and development, and that c) the actuation in the field of technological innovation represented a completely new business area for SENAI at the national level, it may well be valid to use the three main human maturity stages as an analogy for the three corresponding lifecycle phases: from "child" to "teenager" to "adult". The following chapters are dedicated to describing these three lifecycle stages and the respective management system, methodologies and tools which were developed and used to support effective governance on the network level in each phase.

After the initial planning and ramp-up phase, the to-be-developed management system should continuously support the effective governance of the ISI network as a whole. For this purpose, a Network Governance Committee was installed, composed by representatives from SENAI national department, from the involved regional departments and from the Innovation Institutes as well. In regular meetings this committee continuously monitors and controls the evolution of maturity of each institute and takes the relevant decisions to maintain all operational ISIs on a high quality level by fulfilling the national minimum requirements. In case of significant deviations from these minimum requirements, the respective ISI would be set on the status "under observation" (yellow light) and the supporting governance structures would help the ISI to manage the turnaround back to "normal operations" (green light) by the means of coaching and mentoring activities up to comprehensive "rescue programs", if necessary. In the rare case of continuing violation of the network's minimum quality requirements the ISI would be put on the "Exit / Transformation" status (red light) and the Network Governance Committee together with the responsible state's industry federation would decide on measures to withdraw the status of a full-scale Innovation Institute, re-define the scope of the institute and/or re-allocate parts of the respective institute to other entities in the network, assuring that the nationally agreed R&D portfolio continues to be covered by the ISI network. In each phase, the respective lifecycle management system needs to carefully define and monitor relevant criteria to measure the fulfillment of minimum requirements in an objective way in order to support these governance processes systematically.

4.1. Entering the network

The first 25 SENAI Innovation Institutes were led through the initial phase by a structured process of Strategic Business Planning. Based on the methodology "Integrated Strategy Development" (Will, 2012; 2020), a workshop-based approach was chosen in order to stimulate the participation of the regional responsible units and the core team of the respective institute from the beginning of the planning and implementation process. Following the overall strategy of the ISI network (see Figure 2), the standardized process for Strategic Business Planning shown in Figure 4 is clearly focusing on a demand-oriented market-pull approach from the start. The chosen method, originally designed to structure strategy processes in small and medium-sized companies, supports this business-focused view of the institute with the aim to concentrate the initial planning activities on a "contractor" behavior, i.e. prioritizing the successful actuation as a professional R&D provider for the industry.

After an initial phase of preparation and market analysis, a sequence of workshops moderated by external experts was executed to develop a strategic business plan step-by-step. As a first crucial step to define its market-driven strategy, the institute's strategy planning team elaborated and evaluated the main market segments to be targeted. Using the data from the prior quantitative and qualitative market analysis, the industrial sectors with relevant demand were identified and defined by describing their demand for R&D solutions and listing existing and potential customers in the respective sector.

Using an adaptation of the original BCG-Matrix (Henderson, 1970; Will & Wuscher, 2014), these main market segments were then assessed by the strategy planning team on a 10-point-scale in two dimensions:

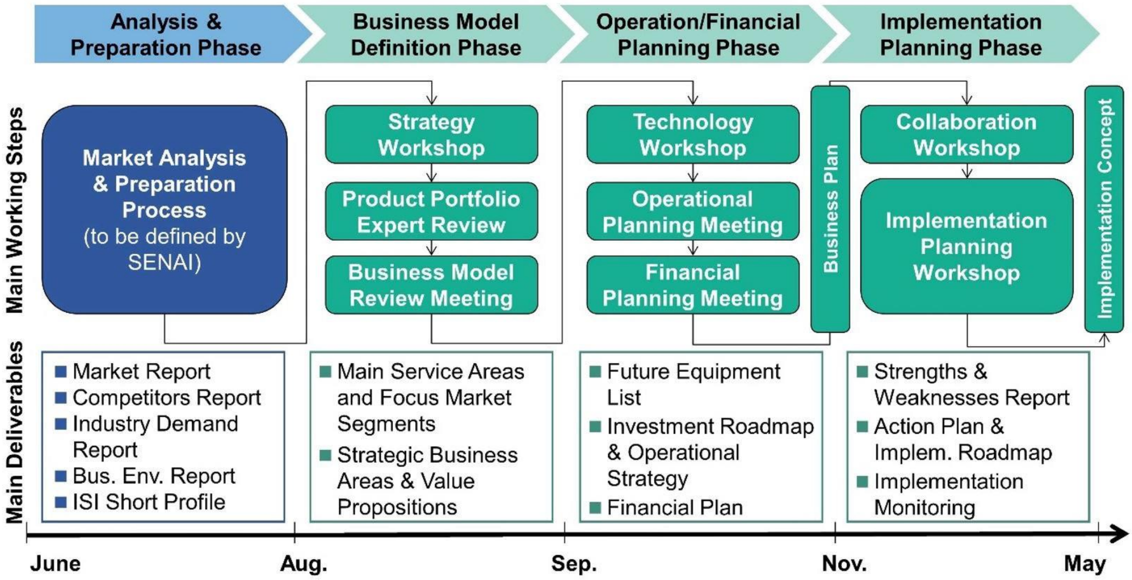

Figure 4. ISI Strategic Business Planning Procedure.

"Market Attractiveness" (demand for R&D solutions in the ISI's research and technology field) and "Probability of Market Entry" (based on existing relations to the sector and general entry barriers of the sector). The resulting Market Attractiveness Portfolio (see Figure 5) serves as a decision basis for a first prioritization of markets to be targeted pro-actively by the institute.

Market Segment	Probability for Market Entry	Market Attractive-ness
Market Segment 1	2	9
Market Segment 2	6	5
Market Segment 3	4	8
Market Segment 4	7	3
...		

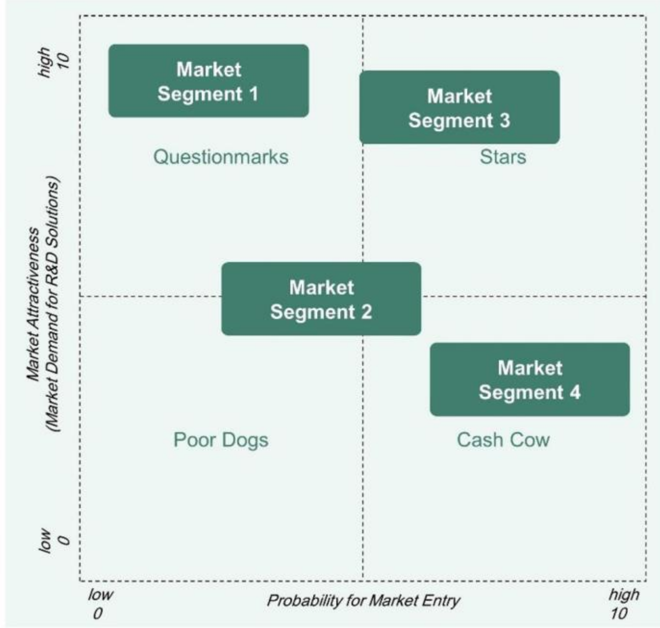

Figure 5. Exemplary Market Attractiveness Portfolio.

As a second step, the R&D offerings of the institute were structured into Main Service

Areas, bundling potential R&D activities in market-oriented packages. Bearing the qualified demand of the prioritized market segments from the first step in mind, the institute's strategy planning team discussed how to structure its service offer for those industrial clients in order to be attractive to them. In a similar methodological approach as in the first step, the Main Service Areas were then assessed by the strategy planning team in two dimensions: "Product / Service Competitiveness" (market demand for own services in relation to potential competitors) and "Product / Service Readiness" (adequacy of institute's competence base and infrastructure for delivering services in respective service area). The resulting Product Attractiveness Portfolio was then used to prioritize those Main Service Areas with high readiness and competitiveness for actual R&D projects to be acquired and executed as first operational activities in the ramp-up phase (see Figure 6).

Products & Services (Main Service Areas)	Product / Service Readiness	Product Competitive-ness
Main Service Area 1	4	7
Main Service Area 2	8	5
Main Service Area 3	3	4
Main Service Area 4	6	8
...		

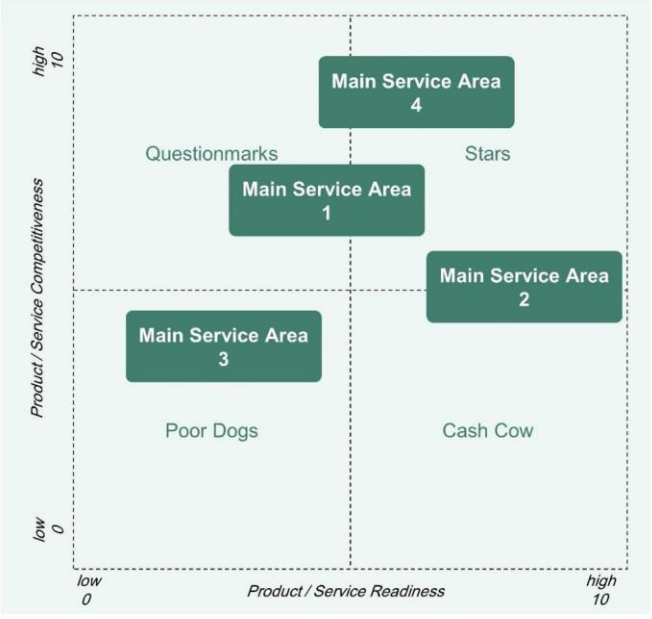

Figure 6. Exemplary Product Attractiveness Portfolio.

While this initial business planning phase for the first 25 SENAI Innovation Institutes used a guided process and a rather prescriptive approach in order to stimulate the necessary mind-setting for this market-oriented applied research model, future institutes will be granted the label "ISI" based on technical criteria and a strategic decision by the network's Governance Committee in order ensure the minimum requirements described above as entry criteria for the network. These requirements include the demonstration of clear and evident industry demand for a certain technology field and a pre-defined service portfolio that complements the national R&D portfolio of the network in a strategic manner. A respective business plan has to be verified by a technical team and be approved by the ISI Network Governance Committee.

4.2. Ramp-up phase

After the successful termination of the initial planning phase, resulting in a business plan agreed by the internal and external stakeholders and investors, each SENAI Innovation Institute was approved to start the implementation process and the first operational activities in parallel. By definition, the "ramp-up" phase is characterized by these two parallel processes and the careful and strategic alignment between these two highly interdependent activities, which was the first practical challenge of the responsible ISI managers. Consequently, a maturity model was defined that puts the focus on exactly this challenge, closely monitoring the evolution of the implementation of the planned infrastructure, service areas and research team as laid out in the business plan on the one hand, and the success in acquiring and executing first research projects on the market, on the other hand. To master this complex task, it was crucial to e.g. align the acquisition of certain equipment and competencies in accordance with the research area which showed the highest readiness (and competitiveness) in the initial business planning, transferring this plan into concrete activities to acquire first projects in this prioritized business area. This is not only important to achieve a first market-entry as fast as possible, generating valuable experience and reputation on the market without waiting for all service areas to be fully set up, but also to use these first experiences and feedback from the market to revise certain parts of the business plan, continuously adapting the strategic development of each institute to the reality on the market. In this way, it was possible to optimize the purchase of costly machinery and equipment as well as the attraction and contracting of adequate research staff according to the real needs of the market.

To track and support this maturity evolution of each institute, a basic maturity model was defined, summarizing the objectives of maturity evolution from planning to implementation, stabilization and excellence phase (see Figure 7). Based on this basic concept, a more specific maturity model was derived to determine the specific stage gates (milestones) of maturity evolution for the particular case of the SENAI Innovation Institutes. Each stage gate is characterized and operationalized by a set of criteria and performance targets which need to be achieved in order to advance in the respective maturity levels of the model. In this manner, a "guided" evolutionary process could be supported in a systematized way which was particularly important for the ramp-up phase, in which most of the ISIs were starting their operational activities from scratch, i.e. without previous experience in applied R&D for the industry. In this phase, a certain "prescriptive" approach was needed to speed up the implementation process and the respective learning curve by providing managerial support according to the specific needs of each maturity level (see Figure 8). The "Maturity Check" operationalized these minimum requirements by a list of criteria for each maturity milestone, and respective evidences being stored in an online repository to allow the remote analysis of the maturity criteria (Kohl et al., 2016).

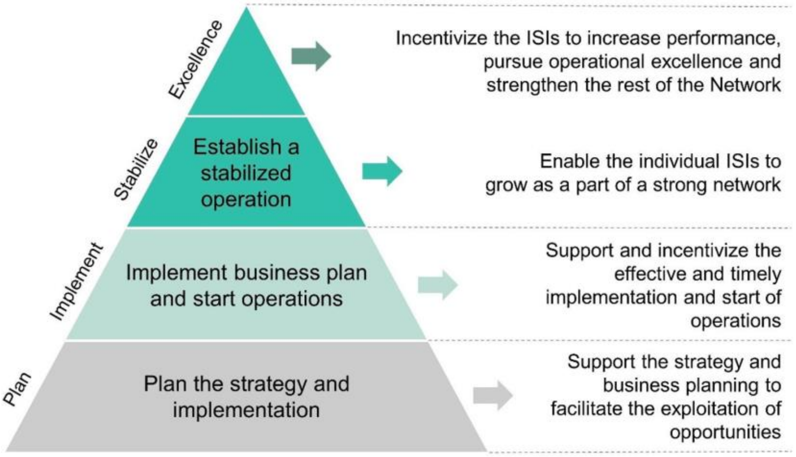

Figure 7. Maturity Concept Model for Applied R&D Institutes.

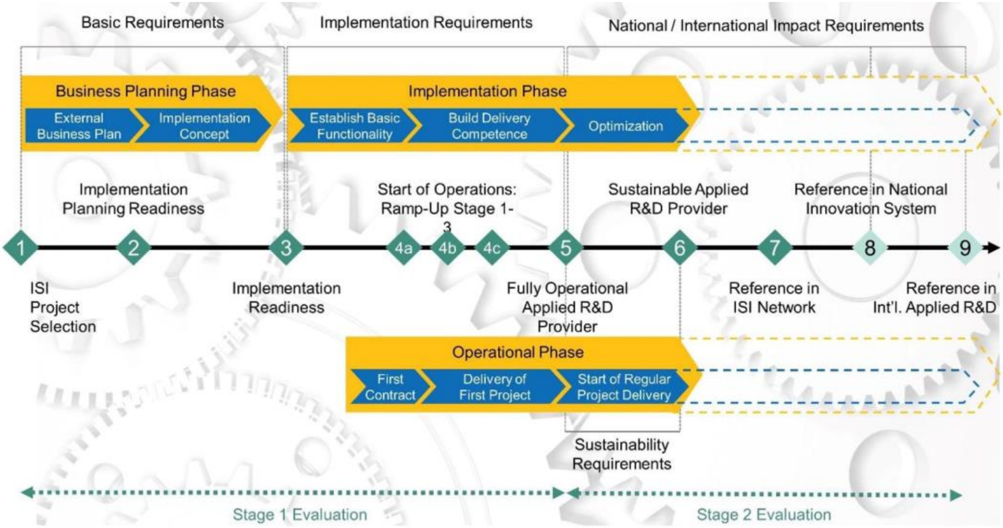

Figure 8. Maturity Stage-Gates Along the ISI Lifecycle.

To support the systematic evolution along the maturity stage gates of the ISI lifecycle, several management tools, techniques and procedures were used and implemented to analyze the internal resource base, to structure the internal core processes and to derive strategic action plans to close the gaps between the defined future status, laid out in the strategic business plans (regularly being updated), and the actual status of maturity of each institute. Among these tools and techniques, the well-proven assessment of intellectual capital regarding the three dimensions quantity, quality and systematic management (QQS Assessment) was used in a structured workshop procedure with a representative team of the respective institute, moderated by experienced external experts (European Commission, 2008; Alwert et al., 2008). The resulting QQS Portfolio, summarizing the assessed actual status of nine success factors for applied research institutes (Kuhlmann & Holland, 1995) against the target status, was then used as a discussion basis to derive the most urgent and important actions to close the strategic gaps in the resource base to advance the implementation of each institute systematically and as efficiently as possible (see Figure 9). Special attention and priority for action was put on those success factors in human capital (HC), structural capital (SC) and relational capital (RC) which showed a relatively low actual status in the quantity and/or quality dimension (X- and Y-axis of the portfolio) as well as a relatively low value in systematic management (size of the bubble in the portfolio), as those factors show the highest improvement potential according to the strategic objectives of each individual institute.

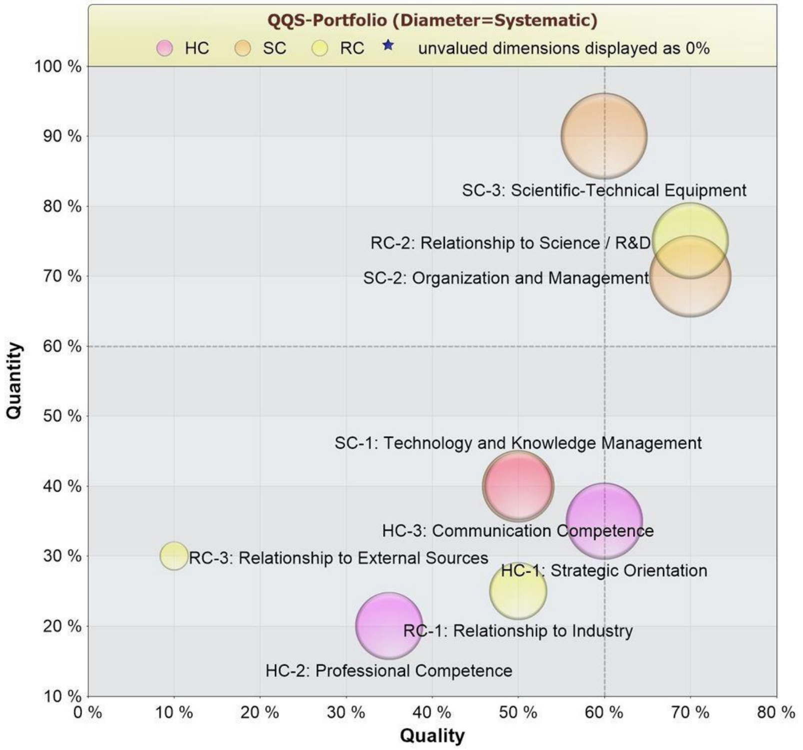

Figure 9. Self Assessment of Institute's Intellectual Capital (QQS Assessment).

Based on the documentation of the structured discussions in the assessment workshop, the main challenges and gaps in those prioritized success factors could be easily retrieved and analyzed in detail to derive the right strategic actions accordingly. This task was performed by the same representative team of each institute in a next workshop session, moderated by external experts. After an initial brainstorming on potential actions to close those prioritized gaps, the collected suggestions were assessed again according to the dimensions Importance, Urgency and Simplicity on a simple 3-point scale, resulting in a ranking to prioritize those actions with the highest impact and relatively low complexity and effort in order to ensure quick wins in this initial ramp-up phase. The resulting action plan was finally transferred to the Implementation Roadmap, displaying the most important actions on a timeline for one year (see Figure 10).

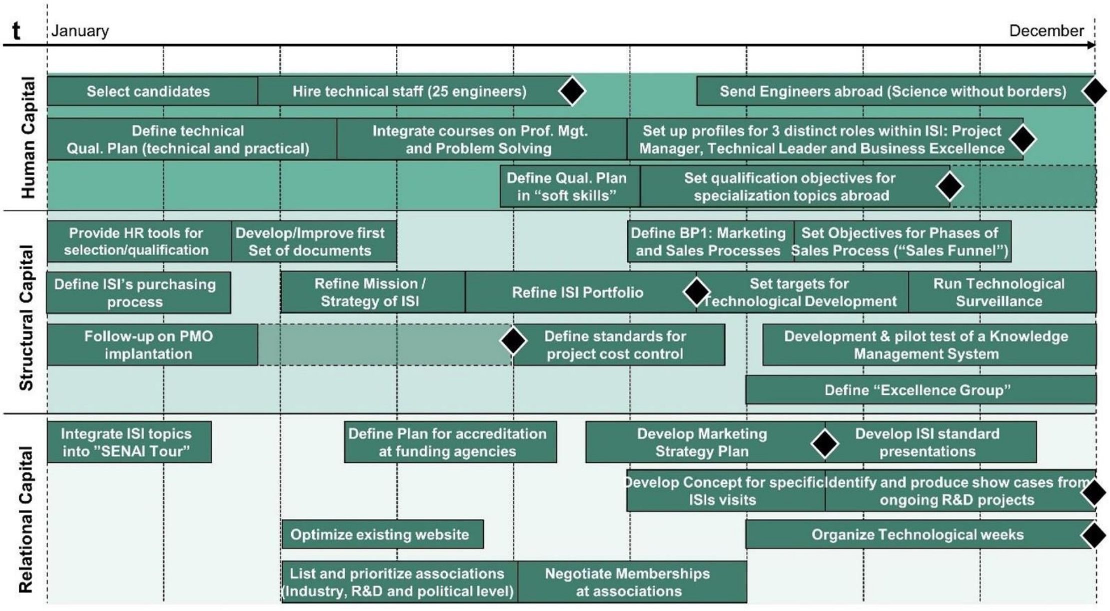

Figure 10. Strategic Action Plan for Systematic Development of Institute's Resource Base (Example).

Procedures for fine planning and monitoring of strategic actions (Alwert & Will, 2014) were introduced to manage the implementation of the strategic actions systematically, generating transparency on the progress of the institute's development and, thus, a basis for regular follow-up assessments by the institute itself and by the responsible regional department in partnership with the national department of SENAI, responsible for coordinating the whole implementation process on the network level.

Based on these initial steps of implementation support, a comprehensive evaluation system was developed, taking into account the maturity levels mentioned above, combining basic organizational requirements, such as a minimum team of researchers and a respective lab infrastructure, with performance targets according to a first set of Key Performance Indicators (KPI), measuring the institute's initial operations, such as first projects contracted and respective revenues.

While this approach and logic of continuous evaluation of the institute's performance and maturity evolution was introduced and established in the ramp-up phase of the ISI network, the full evaluation system was then developed to serve the needs of the next phase of the ISI lifecycle, i.e. the Stable Operations Phase, using a standardized KPI system to operationalize the overall strategic principles and objectives of the ISI network, as introduced above.

4.3. Stable operations phase

After successfully concluding the Ramp-up Phase, which by definition is characterized by the parallel challenges of implementation and initial operation, each SENAI Innovation Institute had to fulfill a set of minimum requirements to formally enter into the Stable Operations Phase. As a "full-grown" institute, the ISIs had to prove that all research and service areas outlined in the business plan had been installed and were operational, as well as to show a certain minimum size of operations by the total revenue and a certain rate of cost coverage by own revenue, among other criteria.

Entering this final stage of maturity evolution, the SENAI Innovation Institutes were now directed to put their focus on a continuous strategic management cycle in order to continuously improve their performance and systematic growth of each institute. For this purpose, and based on the model of Integrated Strategy Development (Will, 2012; 2020) which was already used during the initial business planning phase, a standardized framework for a strategic business model was created which each institute had to fill with individual content to systematize its own business strategy. This framework and standard model then also served as a basis for a comprehensive and integrated evaluation system in the next step of the elaboration of the governance and management system for the whole ISI network.

While the level of the Business Areas, i.e. the R&D products and services and focus market segments of each institute, already addressed in the initial business planning phase, focuses the business question "what are we selling to whom?", the Value Creation Model, as the second part of the strategic business model, aims at answering the question "How are we going to produce the value for the customer and how do we achieve our desired business results?". Based on the framework of the Integrated Strategy Development, and in line with standard management models like Total Quality Management (Zink, 2004; European Foundation for Quality Management, 2010) or the Balanced Scorecard (Kaplan & Norton, 1996) and the respective Strategy Maps (Kaplan & Norton, 2004), the Value Creation Model follows the logic of (1) Resources being utilized in (2) Business Processes, to create (3) Customer Value and (4) Business Success. Taking into account the importance of intangible resources in the case of the knowledge-intensive Innovation Institutes, special focus was given to the Intellectual Capital and the respective success factors for applied research institutions in the "Resources" dimension.

The Value Creation Model itself was developed together with the first SENAI Innovation Institutes in a moderated workshop procedure, discussing the main elements of successful operations. Starting from the right side of the model, i.e. from the business results to be achieved, the leading questions were:

Business Success

- Which overall results do we have to achieve in the mid- and long-term perspective in order to fulfill our mission/vision?
- Which impact do we want to achieve externally?
- How do we measure our overall success of operations?
- Customer Value
- What do our customers value regarding our services?
- What are/will be our main competitive advantages? How do/will we differentiate ourselves from competitors?
- Which position on the market do we want to achieve?
- Business Processes (Value Adding Core Processes)
- Which core processes do we need in order to achieve the defined Business Success?
- How do we acquire projects and generate revenue?
- How do we produce the planned products & services?
- How do we generate the defined value for our customers?
- What are the operational objectives of our Business Processes?
- How do we measure that the objectives are achieved?
- Resources / Intellectual Capital
- Which resources do we need in order to drive our business processes effectively?
- Which success factors are crucial to achieve our strategic objectives and to produce the desired customer value and business success?

- Which knowledge, competencies, structures and relations do we need to be successful?
- Which are our (intangible) assets that differentiate ourselves from the competition?

The overall strategy for the ISI network, its guiding principles and strategic objectives served as a high level starting point for discussing the questions above and thus, defining the main elements of the Value Creation Model and the individual objectives of each element for every Innovation Institute. The outcomes of these discussions with the individual Innovation Institutes were harmonized and aggregated into the following standard structure of the general Value Creation Model of the ISI Network (see Figure 11):

This standardized Value Creation Model now served as the basis for the planning of the strategic actions to implement and continuously develop each institute according to the overall objectives of the network. In parallel, it served as the standard structure for the continuous assessment and evaluation of its operations, and thus, as

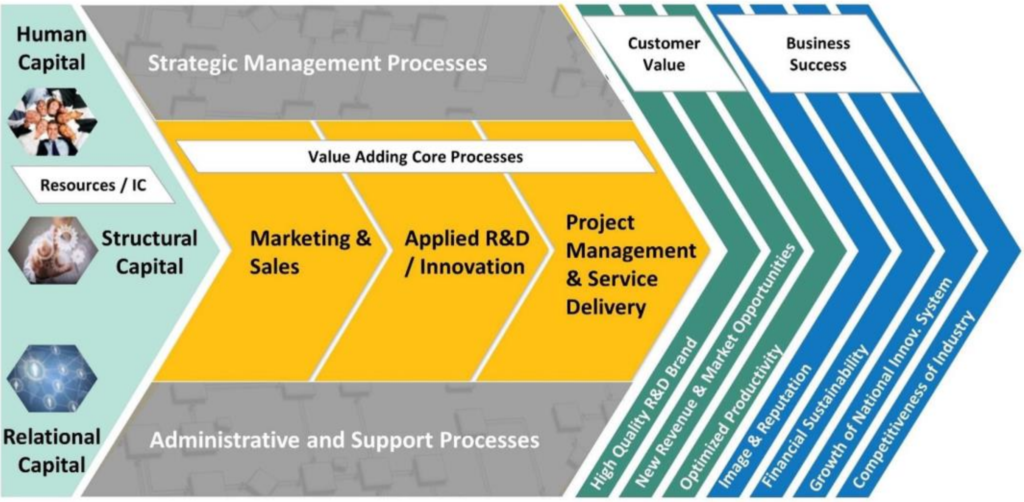

Figure 11. ISI Value Creation Model as a Basis for Strategic Management and Evaluation.

the basis for the development of a comprehensive management evaluation system. Following the maturity model described in the previous chapter, the full evaluation system was now enhanced by a performance monitoring system, using a set of standardized indicators according to the structure of the Value Creation Model.

SENAI's national department then assigned Fraunhofer IPK with executing so-called Management Audits to continuously assess the performance of each institute on-site and to derive a strategic action-map according to the individual gaps and improvement potential to be covered. This one-day workshop was designed as a combination of an audit procedure, checking the adherence of certain minimum requirements according to the maturity model, and a management coaching approach in which the ISI Director discussed the actual performance of his/her institute with a team of selected ISI staff and representatives of SENAI's regional and national department, moderated and coached by external management experts of Fraunhofer IPK. The Management Audit, occurring on-site every two years as the default procedure, aimed at creating a management agreement between the institute, the regional and the national department. This management agreement is registered in a Management Audit Report which summarizes the findings of the actual status and performance of the institute as well as respective actions, investments and support needed to overcome weaknesses and to continue the development towards a full grown and stable R&D provider for the Brazilian industry.

Besides the full audit report with all details of the analysis and derived measures and actions, an executive summary of the audit's findings was produced for each institute, summarizing the main corner stones of the individual strategy in three slides, using the same standard structure of the ISI Value Creation Model to facilitate reading and interpretation of SENAI's management staff in a standardized manner and to ensure a consistent logic of the findings. This logic follows the basic approach of strategic management to 1) (re-)define long-term strategic objectives, i.e. the target status of the business model and its operational performance, 2) analyze and assess the current performance based on a set of appropriate standard indicators, i.e. investigate the actual status, and 3) derive strategic actions to close the gap between the actual status and the desired target status (see Figure 12).

As for the long-term strategic objectives, each of the pre-defined elements of the Value

Creation Model had to be described qualitatively regarding the individual target status by each Innovation Institute. A generic version of this Strategic Objectives Map, valid for the whole ISI network, is shown in Figure 13.

Based on this initial definition of the desired future status, the next challenge was to find an adequate set of indicators to measure relevant attributes of the elements of the Value Creation Model in order to execute the quantitative performance analysis. In a first bottom-up approach, the Innovation Institutes were asked to gather possible KPIs for the main strategic aspects of their business model. This approach follows the principle that the success factors in the four pillars of the Value Creation Model may be operationalized and measured by individual indicators, i.e. defining customized KPIs for each specific strategy and case. Still, the model's standard structure would provide a standardized general framework to allocate and interpret these individual indicators. But of course, the quantitative data and values would not necessarily be comparable among the different institutes. Therefore, to achieve the requirement of a unified governance of all institutes inside the

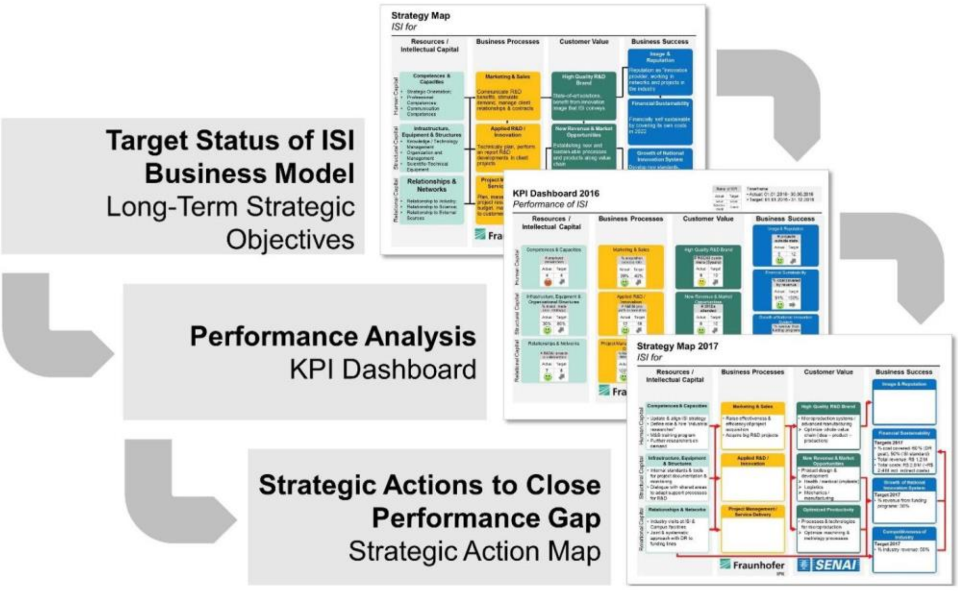

Figure 12. Basic Logic of Management Audit – One Model, Three Consistent Tools.

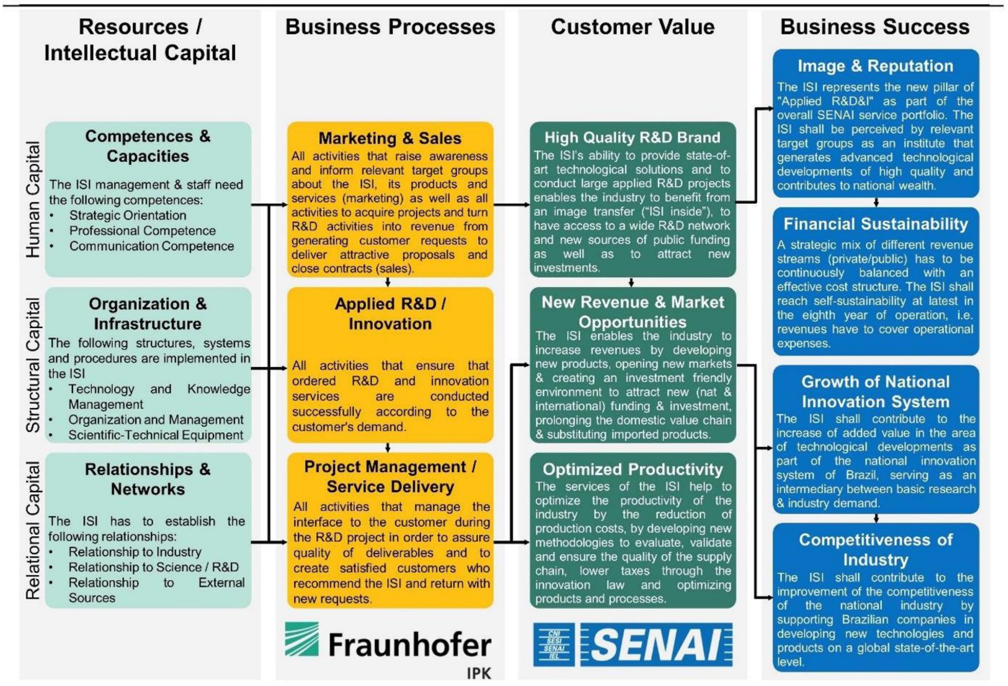

Figure 13. Strategy Map with Long-Term Strategic Objectives.

national network, a set of standard KPIs was needed, leaving room and the possibility to add any specific indicators on the institute level later. The logical hierarchy used to operationalize the qualitative description of the Value Creation Model and its elements by quantitative indicators is shown in Figure 14. This hierarchy follows the assumption that indicators may, in the best case, measure relevant aspects of a certain strategy, i.e. a certain part of a business mode, on an objective basis, but that a few indicators can never represent the whole picture and the full complexity of a business or an innovation institute. Therefore, a higher level interpretation

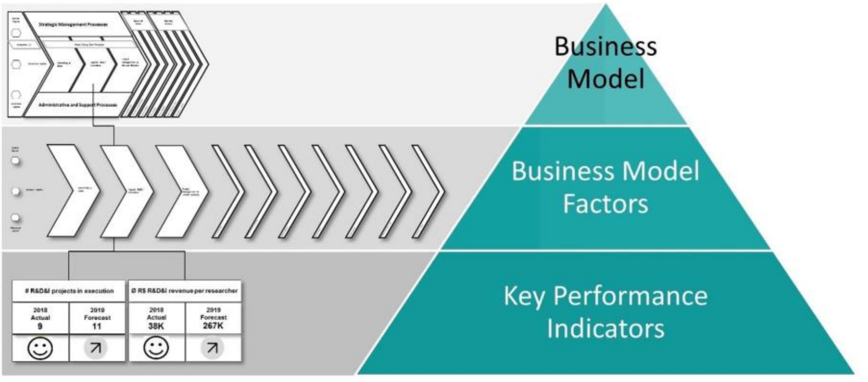

Figure 14. Logical Hierarchy of Levels of Performance Analysis.

context is needed to focus the performance analysis on really relevant aspects and objectives, to be found in the pre-defined success factors and their interplay in the Value Creation Model, as part of the overall Business Model of the SENAI Innovation Institutes.

In order to elaborate this standard set of indicators for the ISI network, a careful selection of indicators had to be conducted, solving the conflicts between validity and the practical measurement process and effort. When trying to measure, for example, the actual contribution to the Customer Value factor "Optimized Productivity", several institutes suggested measuring the actual cost savings at the client companies achieved by implementing a certain technological solution, developed by the respective SENAI Innovation Institute, e.g. in the company's production process. No doubt, this would be the "best" quantitative and objective measure to really know if and how much the Innovation Institutes were helping to improve the industry's competitiveness
– one of the highest strategic goals of the network. But in practice, this kind of data is very hard or impossible to acquire on a reliable basis, as it would rely on the customer's own data which could either be inaccurate or subject to confidentiality, i.e. sensitive internal data that some companies would never disclose. Moreover, it is scientifically difficult to attribute certain causes to a specific effect in a non-controlled environment, i.e. in "real-life" practice where many external and internal factors influence the performance and the productivity of a specific production process (high complexity). In other words: even if a company shows a certain measurable increase in productivity (e.g. same output with reduced costs), it is not automatically proven that this was (only) caused by the introduction of a new technology. Many other causes could also have an effect on these reduced production costs, as for example lower raw material or energy prices, variations in the orders being produced by the respective production process, deviation in the down-time of machines etc. Adding the issue of time lags which many innovations show in terms of producing economic effects, it becomes a very challenging endeavor to try to measure this kind of accurate monetary contribution to a company's productivity. Even if these challenges of data gathering and data interpretation could be overcome by a highly systematic and scientific measurement and analysis process, the necessary effort for this (secondary) measurement would, in many cases, exceed the added value of the respective R&D project, i.e. the actual technological work of the institutes for their clients.

That is the main reason why the set of standard indicators, serving the need of all SENAI Innovation Institutes, had to be somewhat pragmatic in the selection of feasible KPIs, striving for an optimum between validity and the effort for (re-)producing the data analysis. The chosen indicators are the result of a systematic investigation of standards and best practices in the field combined with a systematic discussion inside the national department of SENAI, taking into account the specific requirements and context of the ISI network as well as the individual suggestions from the institutes themselves. Special attention was given to the following criteria when choosing the Key Performance Indicators (KPI) for the SENAI Innovation Institutes:

- Relevance for strategic objectives and operational model of SENAI Innovation Institutes
- Low effort for data gathering (KPI already exists or data is available)
- Semantic link to the Value Creation Model as the interpretation context of the KPI values
- Compatible with other KPIs to perform multi-indicator analysis for comprehensive performance assessment

Taking all of these considerations and pre-work into account, the Value Creation Model was then used to design a one-page "KPI Dashboard", allocating the most strategic indicators to the respective factors of the model (see Figure 15), with the aim to have a full standardized overview and assessment of the actual performance of each ISI at hand, to be used as a management and communication tool inside the SENAI organization.

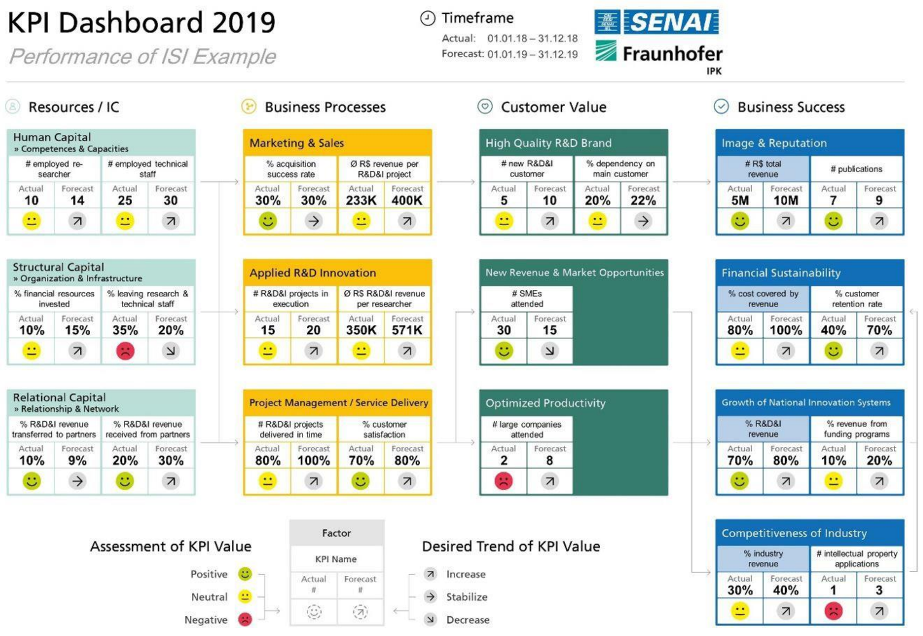

Figure 15. KPI Dashboard with National Standard Indicators for Strategic Performance Assessment (Example).

These KPI Dashboards then served to analyze the performance of each institute regularly, i.e. every three months the respective data was reported to SENAI's national department by the Innovation Institutes, and a mixed team of analysts of SENAI and Fraunhofer IPK assessed these data remotely at the headquarters. On a first analysis level only four basic indicators, highlighted in blue on the right side of the KPI Dashboard (see Figure 15), were being assessed to generate a first overview of the financial and managerial "health" of the respective institute. These four basic indicators, basically measuring the achieved business results of each institute (Business Model dimension "Business Success"), allow a first high-level assessment based on the following interpretation context (see Table 1):

Table 1. Four basic KPIs for first-level performance analysis.

Business Model Factor (Business Success)	Basic KPI	Interpretation of KPI
Image & Reputation	Total Revenue (R$)	
Financial Sustainability	Costs Covered by Revenue ( ) %	

The absolute total revenue of each SENAI Innovation Institute (ISI) indicates the relevance of the institute's work on the market in the overall. A minimum size of the institute (measured by its total revenue), to ensure visibility and recognition by the market, needs to be achieved by each ISI.

To measure the general financial health of the institutes, the share of the operational costs covered by revenue shows the degree of the respective ISI's financial sustainability. An average of 100% has been set as the national target to ensure the financial autonomy of each Innovation Institute.

Growth of National Innovation System	Share of R&D&I Revenue (%)	As ISIs are allowed to also offer basic technological services (metrology, consultancy etc.), the share of revenue made by research, development and innovation projects measures to which degree the ISI is behaving as a "real" innovation institute, and thus, contributing to the national advancement in applied R&D. For full-grown institutes a minimum share of 70% has been defined as a national requirement.
Competitiveness of Industry	Share of Industry Revenue (%)	The share of revenue, coming directly from industrial clients, indicates the relevance of the ISI's service offerings for the industry, and thus, the perceived value of ISI's contributions to the industry's competitiveness. Individual targets are agreed in the Management Audit, respecting a minimum threshold of 30%.

Depending on the result of this First-Level Performance Analysis, the additional KPIs of the dashboard are used to detect possible causes for a certain performance gap in the business results. If, for example, the KPI “Share of Industry Revenue (%)” does not show the desired level of business success (the target value being derived from the strategic objectives of the network and the individual institute), the reason for this under-performance could be a) unattractive R&D offerings and/or unclear business benefits (Customer Value), or b) missing systematic procedures in “Marketing & Sales” for pro-active acquisition of new industry clients (Business Processes), or c) a lack of communication competence and experience in working with industrial companies (Human Capital), or d) a mix of these and other possible reasons. The indicators allocated in the respective pillars of the Value Creation Model may give first hints on the real cause of a certain performance gap, but a qualitative investigation always remains necessary to validate and further analyze a certain management challenge. However, in the shown approach, this investigation can be executed as efficient and focused as possible by starting the performance analysis always from the top level of the business results and, only in case of detected performance gaps, going to deeper levels of the Value Creation Model in a directed way, i.e. in search of evidence and causes for challenges on the top level.

Therefore, and additionally to the quantitative KPI performance analysis based on regular reports of the institutes’ current KPI values and targets, SENAI’s national department requested a yearly update of their qualitative strategic planning regarding the Business Model levels “Markets” and “Products & Services” (see chapter 4.1), i.e. adjustments concerning the focused market segments and the main service areas of the Innovation Institute based on learnings from the market, changes in the business environment and/or internal changes affecting the institute’s strategy. Besides that, formal evidence for the minimum requirements set up by the Maturity Check (see chapter 4.2) was requested as a preparation for the Management Audit. With this input at hand before the actual audit, the moderated discussions during the Management Audit then focused on the verification of the current status and actual performance of the respective Innovation Institute in the light of the previously revised strategic objectives. As a result, the right strategic actions to close individual performance gaps and tackle prioritized management challenges of the institute could be derived and defined.

In the Strategic Action Map those actions are allocated inside the Value Creation Model and interdependencies of the driving factors and desired results (targets) are displayed by directed connections between the Business Model factors indicating specific cause-and-effect chains of the institute’s individual strategy (see Figure 16). Following the basic logic of the Value Creation Model and of the performance analysis described above, the actions are allocated on the left side and aim at closing gaps in Resources/ Intellectual Capital or improving certain performance aspects of Business Processes, to produce certain results and improvements on the right side of the model, i.e. the desired Business Success, including defined revenue targets and target values of other basic KPIs.

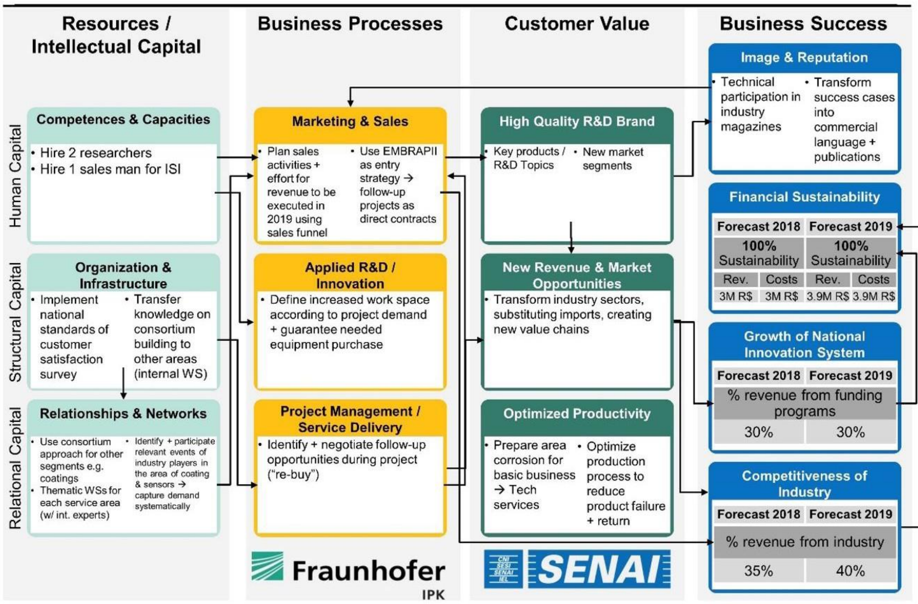

Figure 16. Strategic Action Map with Mid-Term Actions and Performance Targets (Example).

With the Management Audit at its core, the final Evaluation System for the "Stable Operations Phase" of the SENAI Innovation Institutes reflects a lean and pragmatic approach comprising all important information and content to generate a comprehensive and in-depth view of the current situation, i.e. the institutes "managerial health" and the necessary strategic steps for continuous growth. In a one-day workshop procedure, it is possible to generate a full and comprehensive overview of the institute's actual status, its challenges and to create the right action plan for the strategic route each Innovation Institute strives to pursue in a systematic way. This on-site audit is complemented by the Maturity Check to guide through the stage-gates of the Ramp-up Phase, ensuring certain minimum requirements of the national network of Innovation Institutes, and by the regular reporting of the standard KPIs to continuously monitor the performance of all institutes. With these elements established and working, this Management Evaluation System now allows a constant tracking of the evolution of each institute and of the network as a whole, providing objective data and analysis results on performance and management challenges to react quickly and well-directed when significant deviations from the set targets in one of the Business Model dimensions are being detected.

This Management Evaluation System, enhanced by an evaluation of the technological maturity of the Innovation Institutes (not subject of this article), serves as the main building block for the network governance and the respective management system of SENAI to be used for the further strategic development of this newly established national network of applied R&D institutes in Brazil.

5. Results and lessons learned

After the first 5 years of ramping-up the operations, the 25 SENAI Innovation Institutes are counting on the workforce of more than 650 researchers and specialists (approx. 300 of them having a master or doctor degree), supported by a large technical and administrative team at the institutes, as well as at the regional departments and the national department, having already acquired and executed R&D projects for the industry with a total economic value of more than R$ 750 million (approx. 200 million USD). With these impressive growth indicators and a well-targeted strategic development of the ISI network, SENAI is in the process of achieving its overall objectives, helping to transform the industry in Brazil towards a higher level of competitiveness and productivity through innovation and the implementation of new technologies.

After guiding the institutes through the initial planning and ramp-up phase, the main element of the governance and management system for the full-grown national network of the 25 SENAI Innovation Institutes in the "Stable Operations Phase" is the integrated Evaluation System, including the Management Audits described above. The on-site Management Audit is being performed every two years in the regular approach and/or in the case of significant deviations or managerial challenges identified by the regular remote performance analysis (quarterly, yearly). Following the methodological requirement of implementing a lean and pragmatic evaluation system, this audit procedure is possible to be executed in one full day, for more mature institutes and after an initial learning curve it may be reduced to a half-day workshop program. In a last evolutionary step, the main results of this management evaluation are now condensed into one A3-page canvas-like overview which forms the basis of the "management pact" between the Innovation Institute, the respective regional department's directorate and SENAI's national department.

One important learning is that the personal discussions between the institute's management staff and the regional and national department of SENAI at the on-site Management Audit, moderated by neutral management experts and coaches, are crucial for a valid and agreed assessment of performance gaps, for an in-depth investigation of the real causes for these challenges and for the derivation of adequate and feasible actions to tackle these individual gaps and challenges. It is worthwhile noting that the standardized management framework, model and tools including the standardized KPI system work well to streamline the evaluation process, generating verifiable and agreed results regarding the strategic development of each institute, but these data and numbers will never automatically allow a full understanding of the particularities at the institute's site itself, and can never substitute a deep discussion process between the responsible management staff and experienced experts to elaborate the right measures and actions together, creating a common understanding of all involved parties for the reasons and importance of certain actions, which may require investments from the mother organization. Thus, one important purpose of the described models, tools and procedures is to structure and systematize this internal discussion process and to serve as communication instruments inside the organization to guarantee this common understanding.

Besides many external obstacles in the dynamic Brazilian market and political system, one important challenge was and is the adaptation of the mother organization towards the innovation business. Taking into account its 70-year history as a large national organization for technical education, it is somewhat natural that an organization of that size with almost no prior experience in the field of R&D and innovation has to overcome certain barriers of behavioral change inside the various departments and functions that all need to support this highly dynamic and challenging business of applied research for the industry, including HR, finance, legal, purchase, communication and many other supporting departments which still need to be reoriented and empowered to include the requirements of the ISI network in their daily work. This challenge will need a continuous effort in the next phase of the lifecycle of this newly created national network of Innovation Institutes for the Brazilian industry.

While this article has clearly focused on the managerial aspects of planning, implementing and evaluating a national network of applied research institutes in an emerging innovation system, the technological part of this endeavor can, of course, not be neglected. Therefore, the fully integrated Evaluation System also includes a procedure for continuously tracking the technological maturity of each institute and a respective Technology Audit (Hecklau et al., 2019). As an outlook, it may be stated that SENAI and Fraunhofer IPK are planning to enhance this Evaluation System even further in the future, integrating measurements and analysis of impact in the National Innovation System, i.e. for investigating advancements in research and technology as well as in industrial performance on a regional and national level in Brazil.

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ISSN 1980-5411 (On-line version)
Production, 30, e20200051, 2020
DOI: 10.1590/0103-6513.ER3001

Erratum

ERRATUM

In the article **Building up a national network of applied R&D institutes in an emerging innovation system**, DOI number: http://dx.doi.org/10.1590/0103-6513.20190151, published in journal Production, 30: e20190151, page 1:

Where it reads:
Markus Will[a]*, Holger Kohl[a,b], Marcelo Fabricio Prim[c], Alberto Xavier Pavim[c]

It should read:
Holger Kohl[a,b], Markus Will[a]*, Marcelo Fabricio Prim[c], Alberto Xavier Pavim[c]

Where it reads:
How to cite this article: Will, M., Kohl, H., Prim, M. F., Pavim, A. X. (2020). Building up a national network of applied R&D institutes in an emerging innovation system. Production, 30, e20190151. https://doi. org/10.1590/0103-6513.20190151

It should read:
How to cite this article: Kohl, H., Will, M., Prim, M. F., Pavim, A. X. (2020). Building up a national network of applied R&D institutes in an emerging innovation system. Production, 30, e20190151. https://doi. org/10.1590/0103-6513.20190151