Center for
Development Research
University of Bonn

Working Paper 224

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What smallholders can do given the right ecosystem

ISSN 1864-6638 Bonn, September 2023

ZEF Working Paper Series, ISSN 1864-6638
Center for Development Research, University of Bonn
Editors: Christian Borgemeister, Matin Qaim, Manfred Denich, Till Stellmacher and Eva Youkhana

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White Revolution in India

What smallholders can do given the right ecosystem

Ashok Gulati and Ritika Juneja

Abstract

The key objective of this paper is to demonstrate what smallholders can do in the dairy sector given the right ecosystem. India's story of the "white revolution" is a story that can inspire millions in smallholder economies. It has important lessons in terms of government policies that supported and encouraged institutional innovation, infusion of new technologies all along the value chains, and reducing the risk in marketing of milk by smallholders.

India's livestock sector operates on a low-input, high-output model and is sustained by millions of farmers who have an average herd size of less than four animals. India has come a long way from being a milk-deficit country in the 1950s and 1960s to a self-sufficient one with some surplus. The value of milk produced in India today is more than the aggregate value of paddy, wheat, pulses and sugarcane in 2020-2021. The transformation in the milk sector was initially backed by the government through the Operation Flood (OF) program which helped in setting up dairy cooperatives across the country, facilitating collection of milk from millions of dairy farmers to be delivered to processing plants and distributing pasteurized and homogenized milk through thousands of retail outlets in urban cities. Following OF, it was realized that India needed a "double engine force" to boost the dairy sector to meet growing demand of milk in the cities. In 1992, an initial attempt was made to liberalize the dairy sector and open it up to organized private sector players. However, full-scale liberalization only took place a decade later in 2002-03 under the Atal Bihari Vajpayee government, when almost all restrictions related to capacity of private companies to enter the dairy sector were removed and the industry was completely de-licensed. As a result, many private companies began to emerge across the country and procurement volumes were matched within a few years. By 2020-2021, organized private companies procured a slightly larger share of milk directly from the farmers than the dairy cooperatives.

As a result of this "double engine" growth, India produced 221 million metric tons (MMT) of milk in 2022, making it by far the world's largest milk producing country – followed by the US, with 102 MMT. Collectively, the EU countries produce about 155 MMT. India's per capita availability of milk has also gradually improved over the years from 130 grams per day in 1950-51 to 427 grams per day in 2020-2021.

However, dairy farmers continue to face some serious challenges that need to be addressed for a sustainable and efficient growth of India's dairy sector. The large size of the bovine population (more than 300 million) often creates a shortage of feed and fodder for milk cattle. Poor nutrition of animals results not only in lower milk yields, but also exposes them to diseases, like mastitis. Having a large bovine population also has an environmental cost due to the associated high greenhouse gas (GHG) emissions. According to Government of India (GoI) data, 55% of the total GHG emissions from the agriculture sector comes from livestock. One of the reasons behind high methane emissions amongst dairy animals is lack of a balanced diet and poor nutrition.

The GoI and private dairy companies have been spearheading many innovations and technologies in recent years to help overcome these challenges. Some of the technologies gaining popularity in the past few years include assisted reproduction technologies (sex sorted semen), green fodder hydroponics, development of hybrid fodder and utilizing the internet of things for herd management. These innovations and technologies aim to make the dairy value chain more efficient and help smallholder farms by ensuring that production costs are minimized as milk yields increase.

Table of Contents

List of figures and tables

Acknowledgement

The authors would like to thank Ayushi Khurana for her research support in this study. Ayushi was initially involved in this work when data collation and some preliminary analysis was being undertaken, but she left mid-stream for another job opportunity and, therefore, could not be with us for finalizing this study. We are also grateful to R.S. Sodhi, President of Indian Dairy Association, and Chandramogan, the founder and CEO of Hatsun Dairy. We thank Joachim von Braun, Heike Baumüller and Thomas Daum for their comments on a draft version of this study and to Andrew Aziz for his editorial support.

We would also like to express our deep appreciation to the "Program of Accompanying Research for Agricultural Innovation" (PARI) and the German Federal Ministry of Economic Cooperation and Development (BMZ) for supporting this study.

List of abbreviations

AI	Artificial Insemination
APEDA	Agricultural and Processed Food Products Export Development Authority
CH_4	Methane
DoAH&D	Department of Animal Husbandry and Dairying
DoAC&FW	Department of Agriculture, Co-operation, and Farmers' Welfare
DoAH&VS	Department of Animal Husbandry and Veterinary Services
FSSAI	Food Safety and Standards Authority of India
FY	Financial Year
GAVL	Godrej Agrovet Limited
GCMMF	Gujarat Cooperative Milk Marketing Federation Ltd
GHG	Greenhouse Gas
GOBAR-DHAN	Galvanizing Organic Bio-Agro Resources Dhan
ICAR	Indian Council for Agricultural Research
ICMR	Indian Medical Council for Research
INAPH	Information Network on Animal Productivity and Health
IoT	Internet of Things
KMF	Karnataka Cooperative Milk Producers’ Federation
IVF	In-Vitro Fertilization
LLPD	Lakh Liters Per Day
MLPD	Million Liters Per Day
MMPO	Milk and Milk Products Order
MIS	Milk Incentive Scheme
MoDWS	Ministry of Drinking Water and Sanitation
MoEFCC	Ministry of Environment, Forest, and Climate Change
MoHFW	Ministry of Health and Family Welfare
MoNRE	Ministry of New and Renewable Energy
MoSPI	Ministry of Statistics and Programme Implementation
MPC	Milk Producer Companies
MMT	Million Metric Tonnes
NAPDD	National Action Plan for Dairy Development
NDDB	National Dairy Development Board
NDP	National Dairy Plan
NDRI	National Dairy Research Institute
NIANP	National Institute of Animal Nutrition and Physiology
NNBOMP	National Biogas and Organic Manure Programme
OF	Operation Flood
OPU-IVEP	Ovum Pick-up and In Vitro Embryo Production
PBGSBS	Paschim Banga Go-Sampad Bikash Sanstha
RKVY	Rashtriya Krishi Vikas Yojana
SCM	Sub-Clinical Mastitis
SNF	Solids-Not-Fat

1 Introduction

India is a land of smallholders. According to India's Agricultural Census of 2015-2016, the size of an average holding in India was just 1.08 ha. More than 86% of land holdings were of less than 2 ha, which together cultivated about 46% of the cropped area. The Situation Assessment Survey of Farmers for the year 2018-2019 (MoSPI, 2021) puts the average holding size even smaller, at 0.93 ha. This smallness of Indian farms also extends to the dairy sector, where the average herd size is just about 3.25 animals (cows and/or buffaloes) per agri-household, and just 2.06 per operational holding.[1] Given the small holding size, as well as the herd size, it seems most of the Indian farmers are resource poor.

Yet, the story of the Indian dairy sector is unique and holds key lessons for other developing smallholder economies of South and Southeast Asia as well as of Sub-Saharan Africa. A glimpse of this can be seen from the following statistics: In 1951, India's milk production was just 17 million metric tonnes (MMT) while the US was at 53 MMT. In 2020-2021, India produced 221 MMT of milk (DoAHD&F, 2019), making it the largest producer in the world, followed by the US with production of 102 MMT. The EU countries collectively produce about 155 MMT. This remarkable turnaround from a milk-deficit country to a self-sufficient one has been achieved by smallholders. These small-scale producers were incentivized in a new ecosystem characterized by positive policies, institutional engineering (aimed at clustering smallholders in milk cooperatives to scale-up marketing of milk), an infusion of technologies (e.g., simple lactometers, bulk coolers, and pasteurizing and homogenizing plants), and the creation of links to retail outlets in mega metropolitan cities (e.g., Mumbai, Delhi, etc.) in a value chain approach.

In 2019-2020, the livestock sector contributed roughly 30% to the total gross value of output (GVO) of agriculture and allied sector (MoSPI, 2021). Within livestock, the dairy components (milk and bovine meat) contributed roughly 70% to the gross value of the output of livestock. Interestingly, milk is India's biggest agri-commodity, with a value larger than crops like paddy (rice), wheat, all pulses and sugarcane combined. Moreover, the dairy sector employs more than 80 million rural households mainly involving small, marginal and landless farmers. It is interesting to note that more than 70% participation in the dairy sector is by women (Ministry of Agriculture & Farmers Welfare, 2023). Over the years the sector has emerged as a key provider of better nutrition and animal protein.

This study is organized as follows: After this brief introduction of the dairy sector in India, Section 2 describes the evolution of the dairy sector as the largest producer of milk in the world. The role of policies, institutional engineering of milk cooperatives, and infusion of technologies is also discussed in this section. Section 3 covers the current institutional structure of the Indian dairy industry and highlights the growing role of organized private dairy companies. Section 4 briefly discusses the challenges India's dairy industry faces because of a large bovine population, low yields and shortage of feed and fodder. Section 5 presents promising innovations to help address some of the identified challenges. Finally, Section 6 offers concluding remarks on the way forward for India's dairy sector.

[1] As per the Livestock Census of 2019-2020, there were 302.33 million dairy animals (cows and buffaloes). As per SAS 2018-19, there were about 93.09 million agri-households (agri-HH). If one divides the former with latter, one gets an average herd size of just 3.25 animals (cows and/or buffaloes) per agri-HH. If one wants to find out the herd size per operational land holding in India, we have the Land census of 2015-16, which gives the number of operational holdings as 146.45 million. On this basis, the average herd size comes even smaller at just 2.06 cows/buffaloes per operational holding.

2 Evolution of the dairy sector in India

In India, cattle and buffalo rearing goes back to the Harappan Civilization (6000 BC) in the Indus Valley, where seal marks and coins featuring carvings of bulls and zebu cattle have been found (Naik, 1978). Zebu cattle and buffalo were also seen as a major source of both milk and meat (Marshall, 1996). However, as the Vedic period started, the "Doctrine of Sanctity of Cow" began to associate cattle with religious beliefs. India was always known as a land of milk, butter and honey, and even Krishna was often portrayed playing flute in the backdrop of healthy cows on the banks of river Yamuna, or as a child having his hands in earthen pitchers overflowing with homemade butter.

However, with the onset of invaders in India beginning in about 1000 AD followed by the British taking over the reins of power in the year 1757 (first the East India company in 1757 and then British Crown in 1858), the prosperity of India gradually evaporated. When India claimed independence in 1947, both poverty and illiteracy were widespread – affecting more than 75% of the population. By the mid-1960s, India experienced not only acute shortage of basic staples, but milk also had become a scarce commodity. This compelled Indian policymakers to shift their focus from a heavy industrialization strategy to agriculture. The Green Revolution in basic staples (wheat and rice) from 1967 to 1986 and the White Revolution in milk from 1970 onwards, are the two major success stories of Indian agriculture.

At the beginning of the 20th century, the Indian milk sector was largely unorganized. The first organized dairy setup was started by Pestonjee Eduljee in 1915 by the name of "Polsons", following which they established their first plant in Anand (Gujarat). This plant was set up to supply high-quality and sanitary milk to the British army stationed in Bombay (now Mumbai) and other residents of Bombay (Kurien, 2005). Polsons almost had a monopoly in this niche market and dairy farmers associated with the company often raised concerns regarding unfair treatment in payments. At one time, farmers protested by cutting off milk supplies to the company, following which the contract between Polsons and Bombay Municipal Corporation fell apart (Kurien, 2005).

In 1942, Sardar Vallabhai Patel started working towards a cooperative model (which was later popularly known as the Anand Model), and by December 1946 Kaira District Cooperative Milk Producers' Union (KDCMPU) was officially registered. The three-tier model was a producer-driven value chain with federations of milk unions at the village level, district level and state-level (Birthal et al., 2019). The different tiers of the model included:

- **Tier I:** Village Dairy Cooperative Society (DCS): They were formed by the milk producers and farmers and require a membership to conduct any procurement or sale. Village DCSs provide infrastructure to collect milk in the village on a daily basis and offer payments based on quantity, fat, and Solids-Not-Fat (SNF) content.
- **Tier II:** District Union: All district unions are owned by the village DCS and are responsible for processing and marketing the liquid milk procured. Additionally, they provide services to the farmers to promote animal health and sustained growth of milk production. Some of their services include veterinary services and artificial insemination programs, along with feed and fodder supplies.
- **Tier III:** State Federations are mainly responsible for marketing the liquid milk and value-added products produced by member unions under the common brand name. In many cases, these state federations also engage in the manufacturing of feed and support other union activities.

The union managed to grow its procurement of milk from only 200 liters a day in 1948 to 20,000 liters per day by 1952. In 1950, Dr. Verghese Kurien – well known as “the milk man of India” – joined the Kaira District Co-operative Milk Producers' Union (KDCMPU) as general manager and served his tenure until 1973. By 1957, the KDCMPU evolved into Anand Milk Union Limited (AMUL), which soon became a household name in India (Kurien, 2005). In Kurien’s first decade at AMUL, he managed to establish the brand as a leader in milk powder, butter, condensed milk, cheese and baby food – all through strong institutional engineering and technology infusion. He also managed to pool in financial and infrastructure support from a number of sources including UNICEF, the Government of New Zealand (under the Colombo Plan) and the Government of Bombay (Kurien, 2005).

In 1964, Kurien invited Prime Minister Lal Bahadur Shastri to see the operations of this milk cooperative. Shastri spent the night in that village and interacted with farmers. In the morning when he saw farmers from different religions and castes queuing up to pour their surplus milk into a common pot, Shastri reportedly envisaged this as a melting pot of socially diverse groups. The prime minister saw it as not only an inclusive economic model, where a farmer with just one liter of surplus milk can also become a member of the cooperative society, but as an instrument for social integration. He then set up the National Dairy Development Board (NDDB) with Kurien as its first Chairman in 1965.

As the first chairman of NDDB, Kurien prepared his plans to scale-up the three-tier cooperative model across India. His primary goal was to replicate the AMUL model throughout India by ensuring that dairy farmers were empowered to shape the dairy industry free from government interference. Finally, in the 1960s the National Dairy Development Board (NDDB) began planning Operation Flood (OF), which came to be known as “the billion-liter idea”, as it profoundly changed the trajectory of India’s dairy industry (Kurien, 2005). A national agenda was prepared in the fourth five-year plan (1969-1974) to form state-level cooperatives inspired by the Anand model throughout the country.

OF was implemented in three phases over a span of three decades: OF Phase 1 (1970-1980), OF Phase 2 (1980-1985), and OF Phase 3 (1985-1996) (Table 1). The first phase of OF was financed by the sale of skimmed milk powder and butter oil gifted by the European Economic Community (EEC) through the World Food Programme (Kurien, 2004). The second phase was implemented with the seed capital raised by sales proceeds of dried skimmed milk and butter oils along with a World Bank loan of USD 162.6 million and internally generated profits from the sale of the surplus milk. The dried milk received as aid was reconstituted into milk and sold in urban areas at domestically competitive prices during low production years. The remaining stock was used as a “buffer stock” to stabilize market fluctuations and ensure price stability when needed (Kurien, 2004).

By the end of OF Phase 1, India's milk production stood at 30.4 MMT in the Financial Year (FY) 1980 and the per capita availability of milk stood at 125 grams per day (DoAHD&F 2019). The second phase focused on improving the productivity of the dairy herd along with increasing production. Milk production increased at an average annual growth rate of 6.3%, with the per capita availability increasing to 154 grams per day. OF Phase 3 focused on promoting measures to consolidate and sustain the achievements gained during the earlier OF Phases (Sinha, 2007). During Phase 3, although the average annual growth rate of milk production fell to 4.2%, the per capita availability increased to 195 grams by FY 1996 (Figure 1). This phase gave special attention to improving the animal feed and fodder situation by adopting modern animal husbandry management techniques and breed enhancement through artificial insemination (AI).

Table 1: Phases of Operation Flood (1969-70 to 1995-96)

	OF-1	OF-2	OF-3
Duration	**1970 - 1980**	**1980- 1985**	**1985 - 1996**
Investments (Rs. million)	1,165	2,772	13,031
No. of Federations/Apex Milk Unions set up	10	18	22
No. of Milksheds Covered	39	136	170
No. of Members (millions)	1.75	3.63	9.263
Average Milk Procurement (million kg per day)	2.56	5.78	10.99
Processing Capacity Rural Dairies (million liter per day)	3.59	8.78	18.09
Processing Capacity Urban Dairies (million liter per day)	2.9	3.5	3.88
Milk Drying Capacity (metric ton per day)	261	507.5	842
No. of AI Centres ('000)	4.9	7.5	16.8
No. of AI Done (million/year)	0.82	1.33	3.94
Cattle Feed Capacity (‘000 metric tons per day)	1.7	3.3	4.9

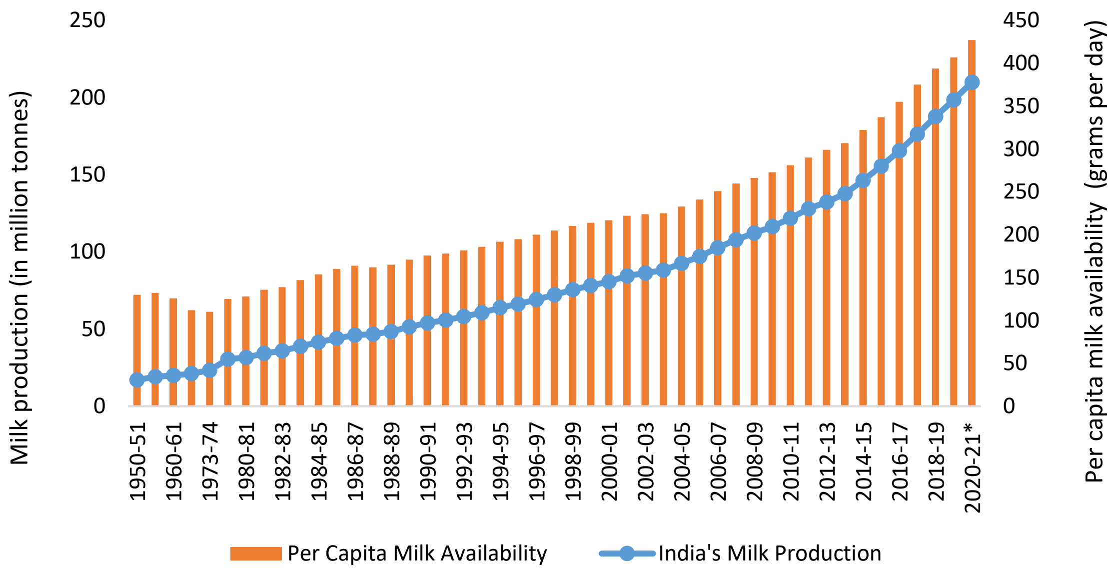
Source: Kurien (2004)

India took advantage of the “mountains of milk powder and lakes of butter oil” (Kurien, 2004) gifted from Europe and changed the trajectory of milk production in India. To this end, the EU-donated milk powder and butter oil was sold by the government in the market. These funds were then utilized to build infrastructure of cooperatives, such as bulk coolers and processing plants. As a result, India transitioned from a highly milk-deficit country to a self-sufficient one, and also the largest milk producing country in the world by FY 1998. As Kurien (2004) said, the “overriding objective of all aid was eliminating the need for aid”. Accordingly, ample physical and institutional infrastructure was created for milk procurement and processing across India to accommodate the surplus milk from some states to sell it to milk-deficit states. While the dairy cooperatives were flourishing, a “double engine growth” strategy for the dairy industry was envisaged to take a further leap forward in the volume of milk it was handling under the organized setup (Kurien, 2004).

Throughout the OF phase, the dairy industry continued to remain highly regulated and protected by the government, with a major tilt in favor of milk cooperatives. The entry of private domestic players in the industry was restricted through the *Industrial Development and Regulation Act, 1951* which had a very restrictive licensing and registrations system. The industry was opened to private players during the economic reforms of 1991 in a move that aimed at boosting domestic investments in the dairy sector and also encouraging foreign investments. However, the change was resisted by cooperatives resulting in the implementation of *Milk and Milk Products Order (MMPO), 1992*, under the *Essential Commodities Act (ECA)*. MMPO imposed restrictions on the capacity of private dairy companies in the name of maintaining a high-quality supply of milk which is procured and processed in hygienic conditions. In effect, these restrictions resulted in barriers to entry of large players interested in the development of the dairy sector and provided virtually monopolistic power to dairy cooperatives.

Finally, it was under the leadership of Atal Bihari Vajpayee that the restrictions on entry of private players were removed, and the dairy industry was completely de-licensed in the year 2003. This deregulation paved the way for private investments in the industry and shifted the focus of MMPO entirely towards sanitary and hygiene benchmarks, food safety measures and other standards adopted by the company. During FY 2004 to FY 2012, milk production recorded an average annual growth rate of 4.4%, which further accelerated to 5.6% during the period FY 2013 to FY 2022. In 2021-2022, the DoAHD&F has projected that India will produce 221 MMT of milk (see Figure 1).

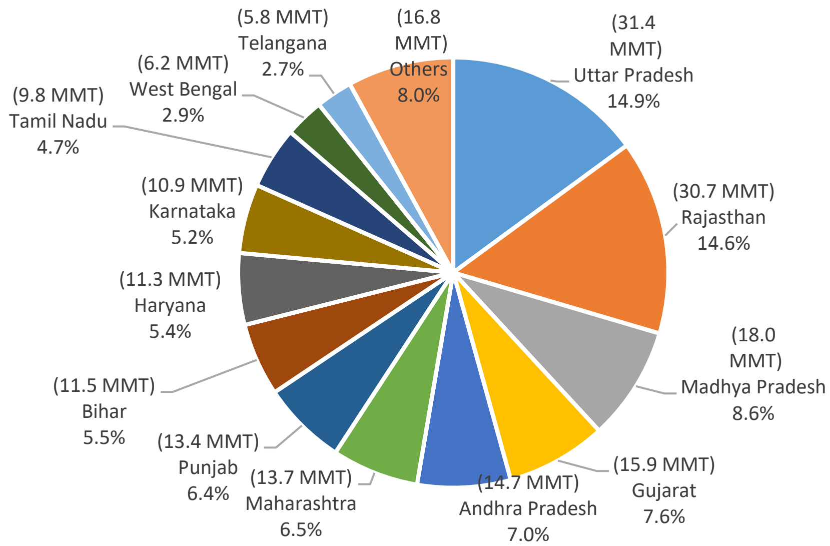
Figure 1: India's milk production and per capita availability from 1950-2021



Source: DoAHD&D (2021)

Within India, Uttar Pradesh is the largest producer of milk, with a share of almost 15% in total production, followed by Rajasthan (14.6%), Madhya Pradesh (8.6%), Gujarat (7.6%) and Andhra Pradesh (7%) (see Figure 2). These top five milk-producing states alone contribute a 53% share in India's total milk production. The remaining milk was produced in different parts of the country in relatively smaller volumes.

Figure 2: India's statewide milk production in 2020-2021



Note: The figure in the parentheses is the volume of milk produced in 2020-2021.
Source: DoAHD&D (2021)

3 India’s dairy industry: Institutional structure and the role of private players

Operation Flood boosted milk production and brought in technologies in the industry to enhance productivity of the large bovine population. It also created a “National Milk Grid”, which connected states with surplus milk to areas with milk-deficit and low production. Even today, the industry remains dominated by unorganized players and only a small share lies in the hands of the organized sector. According to DoAHD&F (2022), 48% of the milk produced in India is retained by dairy farmers and consumed locally in rural areas. The remaining 52% is the “marketable surplus,” which is available for either sale or processing in the market through different players. It is interesting to note that there has been a change in the role of private dairy companies within the organized sector. As of 2021, milk procurement by organized private dairy companies is little more than that of the dairy cooperatives. Despite a late start in the race, private dairies are outperforming the cooperatives in many states across India. The private sector has been quick in adopting new technologies which aid in improving the productivity of dairy herds and increase quality and quantity of milk collected. Out of the 52% of production that is marketed, the unorganized sector has the largest share (31%) and it mainly operates through traditional milkmen, *dudhias, halwais* and contractors who sell their products in loose form. The remaining 21% of production that is marketed came under the organized sector which included dairy cooperatives (10%), private dairy companies[2] (10%) and producer companies[3] (1%) (see Figure 3). The organized dairy players have a fair and transparent system of milk collection at village level and a defined supply chain, while the unorganized sector operates through myriad means from the mandi system (i.e. market yards regulated by Agricultural Produce Market Committees) to directly procuring from farmers. Little reliable data on this latter segment is available.

The seeds for the “White Revolution” were sown during Operation Flood in the 1960s. The model set the base for developing a cooperative model for milk procurement. It was a huge success and, even though the OF ended in 1997, the firm grip of dairy cooperatives and their holistic procurement system can be seen even today. According to the provisional figures released by NDDB (2021), India had a network of 196,114 cooperative dairy societies in 2020-2021, procuring 49.8 MLPD of milk from 17.26 million farmers. Each state has its own dairy cooperative, which processes, markets and sells dairy products under its own brand name. Gujarat and Karnataka’s cooperatives had a large share of 47.4% and 15%, respectively, in the total milk procured by cooperatives in India (NDDB, 2021).

Gujarat Cooperative Milk Marketing Federation Ltd (GCMMF), popularly marketed as Amul, is one of the biggest cooperatives in India (AMUL, 2021). The company registered an annual turnover of USD 5.3 billion in FY 2021 and was procuring an average 2.46 MLPD of milk. The company was engaged with 18,600 village milk cooperative societies, 18 member unions across 33 districts and 3.64 million milk producer members. The second largest procurement was done by the Karnataka Cooperative Milk Producers (KMF) with a turnover of USD 2.2 billion in FY 2021. The company was procuring an average of 7.56 MLPD from 2.57 million farmers and 16,789 dairy cooperatives in FY 2021 (KMF, 2022).

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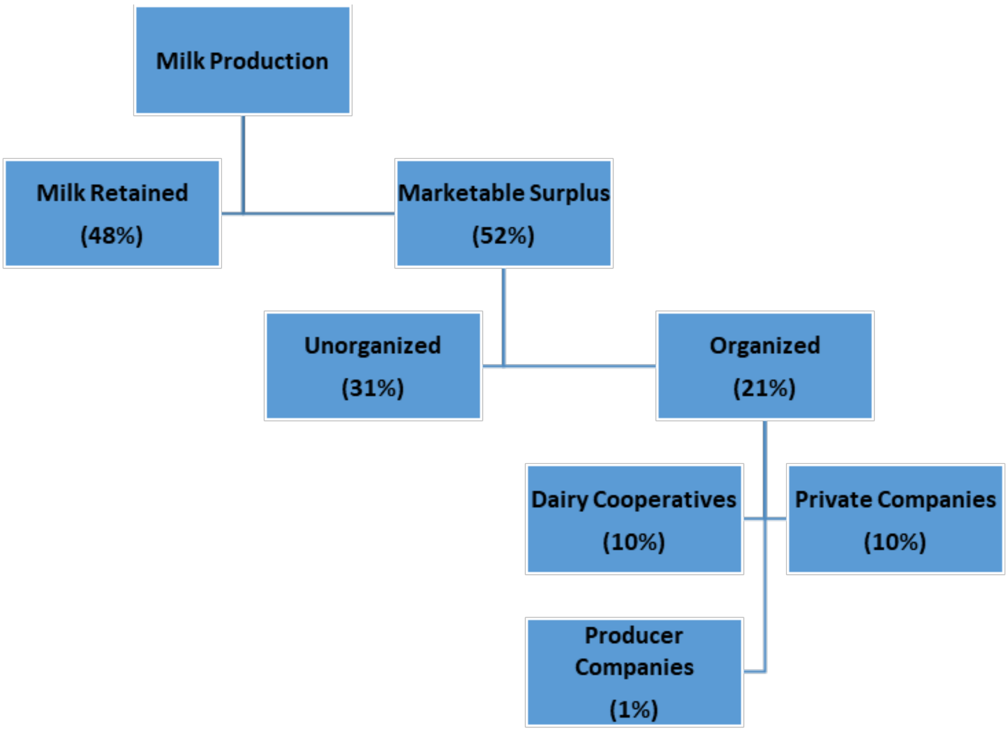
[2] Owned and run by an individual or in partnership as a private business.

[3] Producer-owned enterprise that is "incorporated under provisions of the Companies Act but runs on principles of mutual assistance and managed by professionals

Figure 3: Institutional structure of milk procurement in India



Source: DoAHD&F (2018)

Other state cooperatives such as Tamil Nadu’s (Aavin), Bihar’s (Sudha), Punjab’s (Verka), Kerala’s (Milma), Andhra Pradesh’s (Vijaya) and Madhya Pradesh’s (Sanchi) account for less than 5% of the total cooperative procurement. Despite decades of monopoly and government support, the success of dairy cooperatives has remained highly uneven and geographically concentrated in some states. Some of the largest milk-producing states like Uttar Pradesh, Haryana and Rajasthan recorded very low milk procurement by dairy cooperatives. While the NDDB releases data of milk procurement by dairy cooperatives on an annual basis, there is no reliable data source for the private dairies. The Food Safety and Standards Authority of India (FSSAI) only provides the registration and licensing of dairy plant capacity, which cannot be segregated into private companies and cooperatives. The private dairy companies of India have witnessed a significant growth and expansion in terms of their infrastructure in the last two decades, but it is yet to be captured by any credible agency that can put this data in the public domain.

In 2021, the analytical company CRISIL collected milk procurement volumes of organized private dairy companies for the first time through an extensive survey (the results of which are given in detail in the next sub-section). While these data are encouraging, further data from additional sources on an annual basis is essential (such as the NDDB, which is responsible for the development of the dairy sector as a whole and not cooperatives alone). Absence of a robust dataset on organized private dairies poses challenges in documenting their growth and makes it difficult to formulate policies in support of participation and investment by the organized private sector.

3.1 Growth and milk procurement of leading private dairy companies in India

This section highlights the role of organized private sector dairies, whose contribution has not been duly recognized in the literature on India's milk sector. Private dairy companies were present in India even before 1991, but their number and capacities were limited due to a challenging policy environment. With partial de-licensing in 1991 and complete de-licensing in 2002, private dairy companies were given a level playing field. However, the inflow of foreign capital remained restricted through joint ventures, mergers or acquisitions of local dairy companies (Sinha, 2007). Currently, India has many small, medium and large private enterprises which procure and process milk. The NDDB estimates that the "overall capacity created by private dairy companies in the last 15 years equals that set up by cooperatives in over 30 years" (NDDB, 2011).

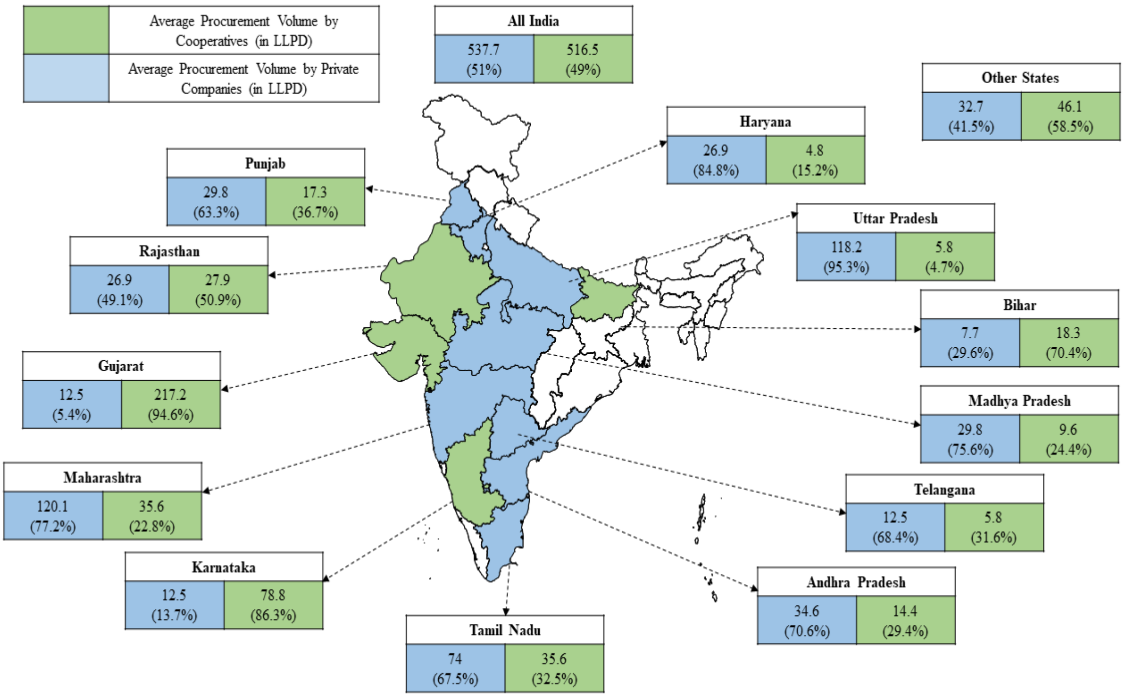
According to the aforementioned survey undertaken by CRISIL (2021), the milk procurement of private dairies in India was slightly more than that of the dairy cooperatives. The estimates show that milk procurement of dairy cooperatives in 2020-2021 was 51.89 MLPD, whereas the private companies procured slightly more milk (53.77 MLPD) during the same year. The study was conducted in the top 12 milk producing states which account for 88% of India's milk production and include some of the largest private dairy companies.[4]

Figure 4 shows milk procurement of dairy cooperatives as well as private dairies in 2020-2021 across the selected states. Out of the 12 states, private dairies in eight states were procuring more milk in comparison to respective state cooperatives. Maharashtra had the highest milk procurement by private dairies with the average procurement volume of 12 MLPD, followed by Uttar Pradesh (11.8 MLPD), Tamil Nadu (7.4 MLPD), Andhra Pradesh (3.4 MLPD) and Punjab (2.9 MLPD). These states were home to some of the largest and most popular private dairy companies in India, which also have a presence in the international market.

In Uttar Pradesh, which is the largest milk producer in the country, private organized dairies had a share of more than 95% in the total milk procurement. Even in Maharashtra, a larger share (77%) of milk is sold to organized players by private sector dairies. A similar story can be seen in Punjab and Haryana as well. In Punjab, private dairies accounted for 63% of the milk procurement being sold to organized players, while in Haryana the share of private dairies was higher at 85%. The dominance of cooperatives was stark in Gujarat where 95% of the milk sold to organized players was procured by cooperatives. Karnataka follows Gujarat, with a cooperative share at 86%, and Bihar cooperatives at 58%. In Rajasthan, the share of cooperatives and private dairies is very close to each other (51% and 49% respectively).

[4] Listed private with procurement of over 0.1 MLPD in each state during the year 2020-2021 were selected for the survey. If the survey had included those private dairies who had daily procurement of more than 50,000 LPD or 25,000 LPD, then the overall share of private organized dairies would be even higher vis-à-vis cooperatives.

Figure 4: Procurement by dairy cooperatives and private companies in 2020-2021



Source: Adapted from CRISIL's report on "Milk procurement by private dairies in India."

In terms of milk procurement, Hatsun Agro Foods Ltd. (HAP) is India's largest organized private dairy, located in Tamil Nadu. HAP holds a strong grip on organized private milk procurement, particularly in the southern states, with a share of 32% in Tamil Nadu, 31% in Karnataka, 7% in Telangana and 5% in Andhra Pradesh (CRISIL, 2021). HAP was procuring on average 3.7 MLPD of milk and has over 20 processing plants. It is associated with 620,000 farmers and has installed more than 10,000 Hatsun Milk Banks (HMBs) in over 13,000 villages.

In terms of sales, Nestlè India Ltd. was the largest dairy in India with an annual sale of about USD 1.1 million (Nestlè, 2021). The company has a strong presence in Punjab (Nestlè India, Moga) and accounted for 25% of the milk procured by organized private companies in the country. The plant was set up in 1961 and has played a major role in working with its milk farmers and suppliers towards improving the quality of milk and productivity of the cattle. Organized private companies[5] – such as Heritage Foods Ltd (1.5 MLPD), Parag Milk Foods Ltd (1.3 MLPD) and Dodla Dairy Ltd (1.2 MLPD) – had a significant share of organized private milk procurement of the country. In addition to these main players, there are other dairies like Bhole Baba (Uttar Pradesh and Rajasthan), Indapur Milk (Maharashtra), Parag Milk Foods (Maharashtra), Schreiber Dynamix Dairies (Maharashtra), Tirumala Foods (Tamil Nadu), Jersey Milk Processing (Andhra Pradesh) and Anik Industries (Madhya Pradesh), which are expanding their scale in India.

Most of the organized private companies procure milk directly from thousands of farmers or milk unions organized by them across different villages (similar to the cooperative model). The milk collected by these farmers is stored in bulk milk coolers and chilling centers set up by the companies

[5] Milk procurement of private companies has been taken from their respective Annual Reports.

within the village to ensure minimum bacterial growth in the milk. Large private companies tend to invest in a modern and reliable supply chain to ensure that the quality of their product is maintained.

India's dairy sector has also witnessed domestic/international mergers and acquisitions which have helped increase the procurement and processing capacities of private dairy companies. One of the most recent and significant mergers was between Lactalis (France) and three local dairies in India. Thirumala Dairy (Andhra Pradesh) was acquired by Lactalis in 2014, after which the company acquired the dairy companies Anik Industries (Madhya Pradesh) in 2016 and Prabhat Dairy (Maharashtra) in 2019 (Lactalis, n.d.). By acquiring these companies, Lactalis opened many opportunities in the biggest and most challenging dairy market in the world. The traditional and cultural experience of Indian dairy companies and global technologies served as an advantage for Lactalis in establishing its presence in India. The company has invested about USD 539.6 million India to create a capacity of 2.5-3.0 MLPD in all three plants. An illustration of the challenging policy environment for private companies

The father of the White Revolution, Dr. Verghese Kurien, backed the development of dairy cooperatives as *a farmer-led development model* connecting milk farmers to lucrative markets in cities. This model gave India its self-sufficiency in milk and improved per capita consumption as well. The cooperative's structure was originally intended to be *independently operating people-based movements,* free from government intervention. While Kurien was at the helm of affairs as the NDDB chairman, he promoted cooperatives with support from the government and worked to minimize political interference. Even efforts by large private sector dairies to enter the market were opposed. As a result, even decades after the OF, cooperatives could not process even 10% of the country's milk production. In some states, cooperatives performed very poorly, and there was much political intervention. It is this limited capacity of cooperatives which finally led to de-licensing of the dairy industry in 2002 under the leadership of Prime Minister Atal Bihari Vajpayee.

While private companies managed to increase procurement and processing capacities based on their own capital and entrepreneurial initiative, the dairy cooperatives continued to receive support from the central government or their respective state governments in some form or another.

Implemented in 2012, Phase 1 of the National Dairy Plan (NDP) was one such scheme started by the Center which aims at increasing productivity of milk animals to keep up with rising domestic milk demand. Interestingly, it does so only for farmers that are in the ambit of milk cooperatives and does not accommodate organized private dairies. Similarly, the National Program for Dairy Development offers financial assistance to create and strengthen infrastructure for milk processing and cold chain storages. The program offers a 50% grant in aid to dairy cooperatives and Farmer Producer Organizations and excludes private dairies from such benefits.

Two cases – Gujarat and Karnataka – shall be visited in more detail in the following:

3.1.1 The case of Gujarat: Large export subsidy on skimmed milk powder exports to GCMMF

Milk is largely traded in the international market in the form of skimmed milk powder. Most of the cow milk in India has a 4% fat and 8% SNF, whereas buffalo milk has 6% fat and 9% SNF. About 12 liters of milk is required to produce 1 kg of skimmed milk powder with 3% moisture which is ideal for exporting and storing milk. The largest cooperative of India, Gujarat Cooperative Milk Marketing Federation Ltd (GCMMF) tends to hold large volumes of skimmed milk powder at any point of time. In order to ensure an optimum price and profits, the state government announced incentive support of USD 0.67 per kg for skimmed milk powder for exported milk which is about 20-25% of the freight on board price for skimmed milk powder exports. The support provided by the government is capped at USD 202.4 million for the period July 1, 2021 to December 31, 2021. The aid is distributed through the GCMMF which has about 18 district dairy unions that sell dairy products under the Amul brand (Vora, 2021).

This outlay of USD 202.4 million to GCMMF would allow it to sell between 30,000 - 50,000 tons of skimmed milk powder in the international market with a better price realization. However, while international skimmed milk powder prices have fallen by about 9.5% since May 2021 from USD 2.8-3.4 per kg to USD 2.60-3.10 per kg, the cost of production for Gujarat dairies remains the same as before (Vora, 2021). resulting in a net loss of about USD 0.67 per kg for the cooperative. The subsidies offered to cooperative dairy farmers protect them from the global price fluctuations but distort the market for private sector players in skimmed milk powder exports and therefore discriminates against them.

The trend of offering subsidies to clear skimmed milk powder stocks has also been seen in previous years when support of USD 0.67 per kg was given from November 1, 2020 for a period of six months, and earlier in 2018 also. A total sum of USD 35.07 million has been given in the form of subsidies to safeguard farmers' interests in the face volatile global prices of skimmed milk powder. The continuous flow of subsidies reflects the financial fragility of India's largest cooperative dairy that had a sales turnover of USD 5.15 billion in FY 2020.

3.1.2 The case of Karnataka: Milk Incentive Scheme

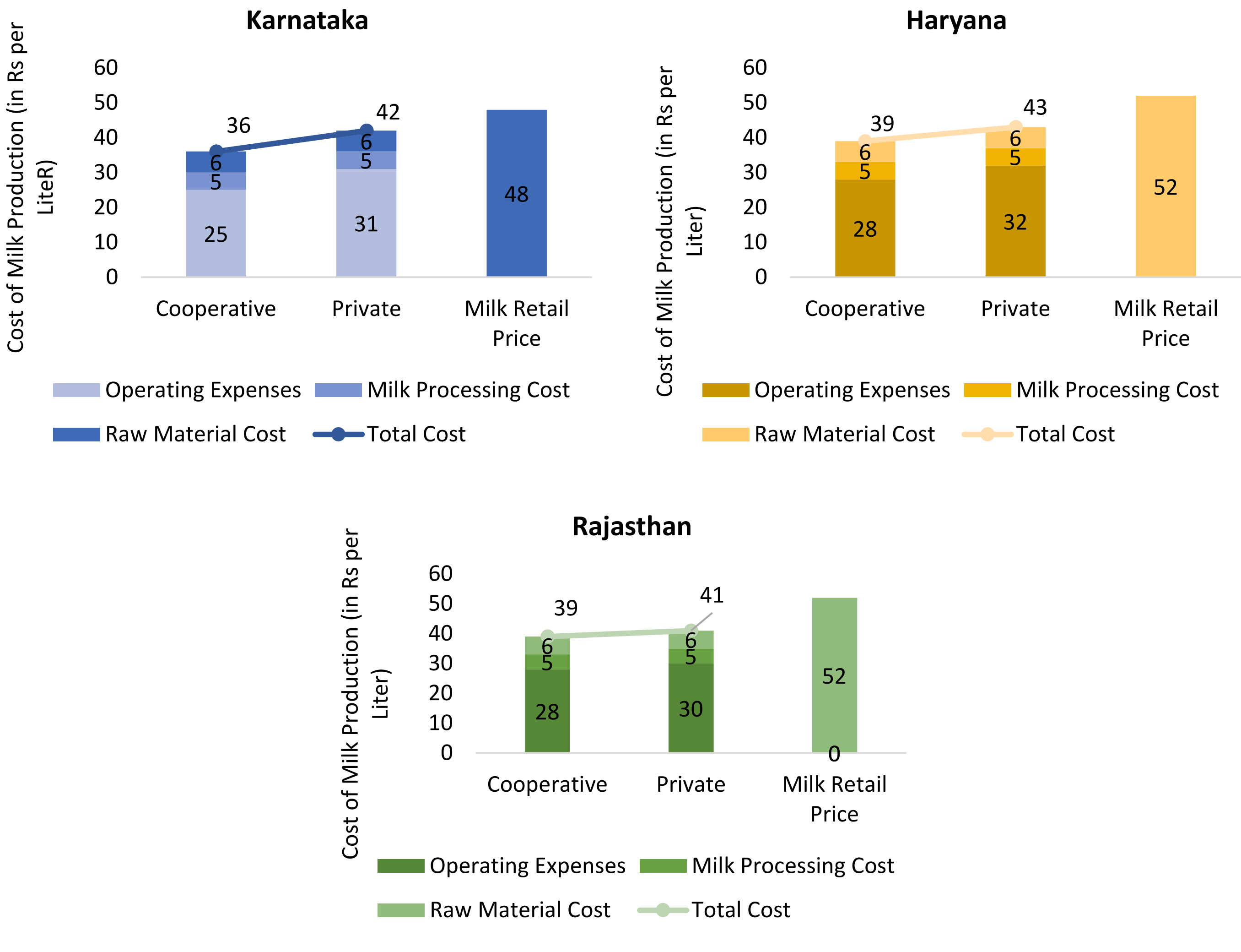
The Karnataka Cooperative Milk Producers' Federation (KMF) holds a dominant position in milk procurement in Karnataka with an average procurement of 7.44 MLPD. It operates under the brand name "Nandini" and has the second-largest cooperative procurement of milk in the country after GCMMF. Farmers who pour their milk into KMF benefit from the "Milk Incentive Scheme" (MIS) of the Department of Animal Husbandry and Veterinary Services (DoAH&VS) of the Karnataka government. MIS started in July 2008 by providing an incentive of USD 0.04 per liter of milk poured by farmers into the cooperatives which was later increased to USD 0.06 per liter of milk in May 2013 (DoAH&VS, 2020). By November 2016, this incentive was increased to USD 0.07 per liter of milk, all backed by increasing financial grants by the government (Damodaran and Biswas, 2018). As of July 2021, under the MIS cooperative, dairy farmers are receiving an incentive of USD 0.08 per liter of milk, which helps the government of Karnataka keep the retail price of Nandini milk low.

According to the estimation of CRISIL (2021), a subsidy of USD 0.08 per liter given to co-operatives farmers increases the cost of raw material for private dairies by as much as 24% in relation to cooperatives. Other states such as Telangana, Haryana and Rajasthan also offer subsidies to their respective dairy cooperatives which translates into higher procurement prices and increased cost of procurement for private dairies. Both Telangana and Haryana offer a USD 0.053 per liter subsidy to cooperatives, increasing the cost of raw materials for private dairies by 15% and 14%, respectively. Similarly, in Rajasthan a subsidy of USD 0.02 per liter increases the cost by 7% for the private dairies procuring in the state.

Figure 4 shows the break-down of costs for dairy cooperatives and private dairy companies in the selected states. The cooperatives manage to keep their raw material cost low by utilizing the subsidies they receive from state exchequers and offer more remunerative prices to the farmer. The cost of raw materials is visibly high for private dairies in these states in comparison to the dairy cooperatives.

These subsidies artificially increase procurement prices for private companies, which have no option but to offer competitive milk prices in the retail market. Private dairies end up squeezing their own profits in such cases and eventually become unviable in expanding their operations. This is quite clear in the case of Karnataka, where private sector dairies have been almost completely "crowded out." This does not augur well for developing a competitive dairy sector. It would be much better if the state support to farmers is given for increasing productivity through better research and development, and genetic improvement rather than price subsidies on their output. Literature is abound with distortions in milk prices across several countries[6] (OECD data base on Producer Support Estimates), more so in high-income countries. India is one of the few countries which has in fact negative net producer support to its agriculture despite some subsidies here and there. This is done by putting export restrictions whenever domestic prices rise (OECD, 2018). Marginal returns in Indian agriculture are much higher on agricultural R&D than on subsidies (Gulati, Ferroni and Zhou, 2018).

Figure 5: Cost of milk procurement in states offering subsidies to dairy cooperatives



Source: CRISIL (2021)

[6] For further information, see https://www.oecd.org/switzerland/producerandconsumersupportestimatesdatabase.htm.

4 A critical evaluation of the dairy industry in India

India’s dairy sector is dominated by millions of small and marginal farmers living in rural areas with limited access to modern facilities, technologies and innovations. The smallholder nature and limited incentive for farmers to make investments have raised several challenges, especially with regard to raising productivity and making the Indian dairy sector globally competitive. Despite having the largest dairy herd in the world, yields are very low (roughly 8 kg/day for exotic/crossbred cows, 3 kg/day for non-descript/indigenous cows, and 5.6 kg/day for buffaloes) due to lack of adequate nutrition arising out of a shortage of feed and fodder in the country as well as low potential genetic material of indigenous cows. The large herd is also a contributor to greenhouse gas (GHG) emissions in the form of methane (CH_4) and nitrous oxide (N_2O), which are byproducts of their digestive process. In this section, these challenges and their impact on the progress of the Indian dairy industry are discussed.

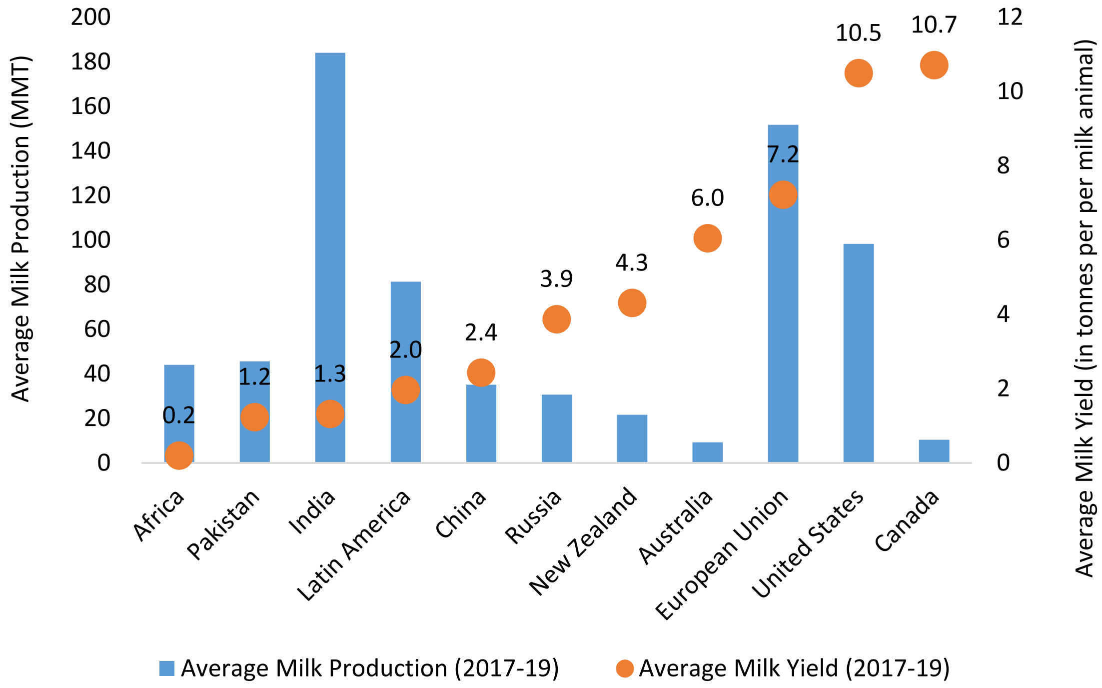
4.1 Low milk yields and a large dairy herd

Shortages of feed and fodder often results in lower productivity of the dairy herd. Between 2017 and 2019 the average yield in India was only 1.3 metric tons per in-milk animal. The yield was starkly low in comparison to other leading milk producing countries of the world (Figure 5), including the United States which had an average yield of 10.5 metric tons followed by the European Union with a yield of 7.2 metric tons, and New Zealand with a yield of 4.3 metric tons for in-milk animals (OECD, 2020). Evidence suggests that Indian dairy farmers try to compensate for the low milk yield by increasing their herd sizes without properly accounting for the cost of rearing and feeding the herd, as it is largely handled by family labor in the backyard of a house. This often becomes counterproductive as it increases the pressure on limited resources of the farmers and also adds on to the GHG emissions of the agricultural sector (discussed in section 4.4).

As of 2018-2019, India had 192.5 million cows, out of which 21.4% were crossbred/exotic cows with an average milk yield of 7.9 kg per milk animal per day (DoAHD&F, 2020). Despite their relatively higher productivity, their share in total population remains limited as they are not able to adapt to the tropical climate, making them vulnerable to diseases which results in a shorter life span. The remaining 78.6% of the cows were either indigenous or nondescript breeds which are native to India. The indigenous and non-descript cows have an average yield of only 3 kg per milk animal per day with a small share of 10% and 11% in the total milk-production during 2018-2019.

Low genetic potential coupled with limited quality feed and fodder has impaired the potential of dairy farmers to increase milk production. The number of animals has far exceeded the resources farmers have to manage and feed them. It can be assumed that India's milk production has been backed by horizontal growth with the growing number of animals while the need of the hour is to achieve vertical growth by improving productivity of the existing herd.

Figure 6: Milk production and in milk yield of selected countries



* Note: The yield is calculated per milking animal (mainly cows but also buffaloes, camels, sheep and goats).

Source: OECD (2020)

4.2 Shortage of feed and fodder

According to the 20th Livestock Census, the livestock population of India increased by 4.6% between 2012 and 2019 (DoAHD&F, 2020). The population of the dairy herd, which includes cattle and buffaloes, increased by 0.8% and 1.1%, respectively. In 2019, India had 302 million cows and buffalos. The increase in the dairy herd increased the need for more feed and fodder, which were already in short supply. Estimates by the Indian Council for Agricultural Research (ICAR) show that India is likely to have deficit of 68.1 MMT (11.9% deficit) in dry fodder and 224.2 MMT (24.5%) in green fodder by 2030 (ICAR, 2018). The supply of both fodders is expected to remain in deficit until 2050: dry fodder supply in deficit by 83.3 MMT (13.2%) and green fodder supply in deficit by 186.7 MMT (18.4%). While the growing demand for fodder is one of the main reasons for the fodder shortage in India, there are other supply factors which are placing further pressure on deficit volumes.

Availability of crop residues as fodder has declined over time as farmers adopt advanced technology and mechanization. Farmers prefer using high-yielding dwarf varieties, mechanical grain pickers and harvesting equipment, which significantly reduces field wastage and crop residues of cereals (DoAHD&F, 2016). Also, the cropping pattern in India is skewed towards wheat and rice, particularly in northern states, as the incentives to grow such crops are high (such as minimum support prices and open-ended procurement), which are not suitable for animal feed and fodder. In addition, there is a very small share of the area which is exclusively devoted to improving green fodder (due to a lack of data, it is difficult to assess the volumes and trends across states). The area under fodder cultivation during 2013-2014 was only 4% of the total cropped area, and it is expected that the area would have reduced even more by 2021-2022 (DoAC&FW, 2019).

The reason for the small fodder cultivation share lies in limited land in relation to population. Although almost half of India's geographical area can be cultivated in some form or another, there almost half (46.5%) of the workforce depend on it (2020-2021). The opportunity cost of growing fodder on scarce land is high, and often the choice is in favor of grain crops. With growing urbanization and population, it is expected that the land available for pastures and grazing eventually be encroached on by the expansion of cities. This growth in urbanization would further reduce the availability of pasture for livestock grazing in the coming years and add to the problem. The shortage of green fodder has pushed farmers to often give concentrates with blended grains, brans, protein meals/cakes, agro-industrial by-products, minerals and vitamins to their livestock. While these meals are nutrient rich, farmers have limited income to buy these due to their high prices. As a result, a large segment of India's dairy herd lacks essential minerals and vitamins, impacting their productivity and making them vulnerable to diseases. The shortage of fodder has also resulted in abandoning unproductive cattle and buffaloes. They are often left to starve or given low-quality crop residuals which impacts their digestive systems resulting in higher GHG emissions.

4.3 Economic impacts of mastitis on the dairy industry

Dairy industries across the world are impacted by mastitis and sub-clinical mastitis (SCM). The affliction negatively impacts not only animal health and milk quality, but also the overall economics of milk production. Abutarbush (2010) defines mastitis as an "inflammation of the parenchyma of mammary glands characterized by physical, chemical and bacteriological changes in milk and pathological changes in glandular tissues." With SCM, there are no visible changes in the physical appearance of milk or the udder, but the productivity of the animal and the quality of milk is affected (Langer et al., 2014). Because it is an invisible disorder, it requires continuous surveillance, milk testing and monitoring for early detection. Otherwise, it may lead to higher economic costs.

Bacterial infection in the intra-mammary region is one of the main causes of mastitis or SCM in bovine animals such as cows and buffalo. While there are a host of reasons behind the development of this bacteria, Lakew et al. (2019) divide the disease into contagious and environmental mastitis. The contagious mastitis can be transmitted from cow-to-cow, especially during milking, and the pathogens live on the cow's udder and teat skin, colonizing and growing into the teat canal. On the other hand, the environmental pathogens are often on the bedding and housing of the herd. The incidence of mastitis is contingent on many factors, including breeding and genetics, nutritional stress and the external environment in which the cows live.

According to Shaheen et al. (2016), genes and breed of the dairy cow determines how susceptible or resistant the cow is to mastitis. Usually, pure breed or crossbreed of high-yielding cows like Holstein-Friesian cattle and Jersey are more vulnerable to mastitis than are breeds giving medium yield. In 2019, India had 50.4 million exotic/crossbred cows which is 21.4% of the total cow population (DoAHD&W, 2020). With more and more AI programs popularizing rearing of exotic/crossbred breeds, it is important to accommodate the cost of treating SCM and any possible economic losses which farmers may have to bear.

Furthermore, lack of proper nutrients and energy in the dairy herd post or during lactation impacts the immune system of the cow and increases susceptibility to infections (Matsui, 2012). India's dairy herd is perpetually subject to deficit diets and lack of adequate nutrients which makes it highly vulnerable to developing diseases like SCM. One of the main causes of SCM in a smallholder and informal dairy industry like in India is the environmental conditions and management practices. A large number of animals in a small area, contaminated floor, wet bedding and poor ventilation coupled with a hot and humid climate can create a suitable environment for growth of mastitis pathogens and increase the incidence of SCM among the herd (Abebe et al., 2016). Kumari et al. (2018) highlight that SCM is 30-40 times more common in the dairy herds of India compared to clinical mastitis and it has become one of the major causes of economic loss in the Indian dairy sector. The prevalence of SCM was highest in Madhya Pradesh (62.4%), followed by Punjab (53.2%), Haryana (51.8%), and Uttar Pradesh (39.5%). NDRI (2019) also considers mastitis as a major cause of concern among the Indian dairy herd which causes a loss of around USD 1 billion per annum. SCM also tends to impact the milk composition by altering the level of protein, fat, SNF, lactose levels and calcium in the milk (Cinar et al. 2015). This has a direct impact on the market value of the milk for direct consumption and processing adding to the losses (Ma et al., 2000). India needs to focus on reducing the vulnerability of its large dairy herd to diseases like mastitis and SCM by adapting precautionary measures such as managing nutrition intake, proper maintenance of milking equipment and cattle sheds, and ensuring that the infected animals are excluded from the main dairy herd.

4.4 Rising greenhouse gas emissions from dairy herds

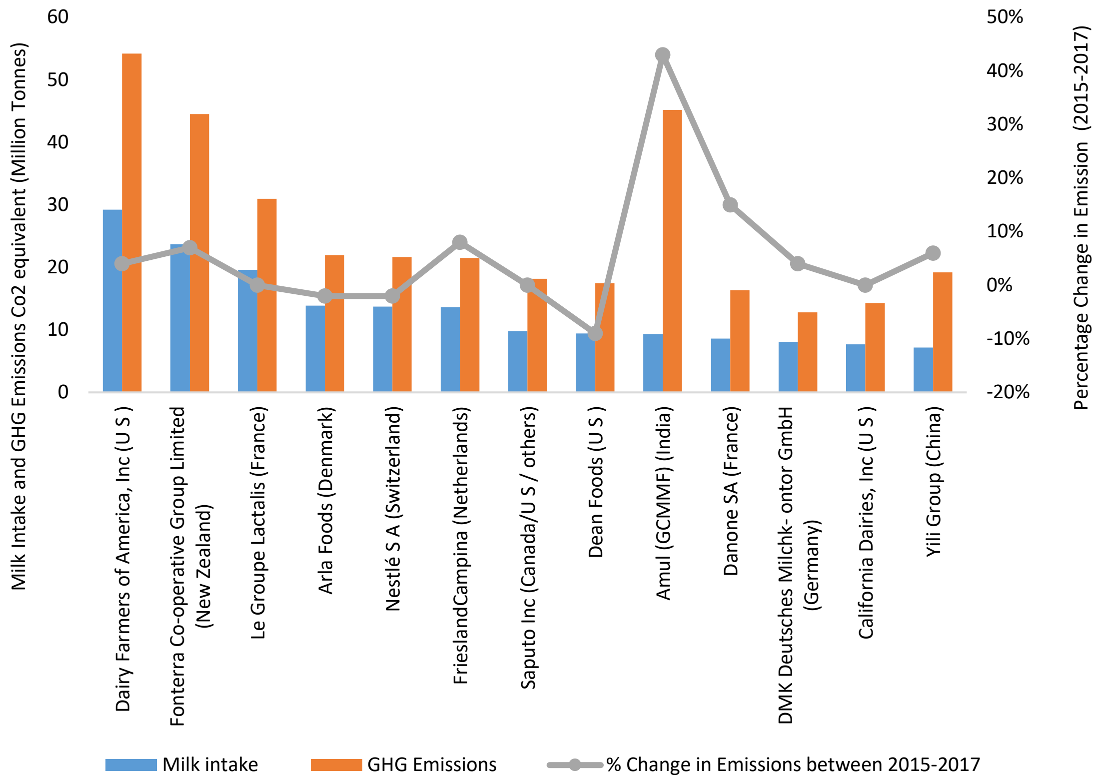
With numbers in excess of 302 million, India is home to one of the largest cow and buffalo populations in the world (DoAHD&F, 2020). The large herd has been an important driver in making India the largest milk producing country in the world, but at a cost of increasing GHG emissions. In 2016, the agriculture sector emitted 407.82 MMT of carbon dioxide (CO_2)-equivalent GHG gases, of which 54.6% were accounted for by enteric fermentation and 6.7% for manure management (MoEFCC, 2021).

Enteric fermentation is the natural digestive process during which celluloses, fiber, starches, and sugars are fermented and broken down to produce hydrogen (H_2), CO_2, and CH_4 (FAO, 2021). The gases are released into the environment through flatulence, belching, and through their manure. There are other by-products such as acetate, propionate, and butyrate which are absorbed and used as energy to produce milk, meat, and wool (FAO, 2021). Emissions from enteric fermentation were predominantly in the form of CH_4, which had a share of 73.5% in total CH_4 emissions from agriculture. The CH_4 released during the enteric fermentation is a short-lived pollutant with a lifespan of 12 years and the ability to trap 84 times more heat than CO_2 (FAO, 2021).

The second source of CH_4 from the dairy sector comes from mismanagement in storing and treating cow and buffalo dung under low oxygen or anaerobic conditions (MoEFCC, 2021). The process produces high volumes of CH_4 and N_2O which had a share of 0.83% and 23.6% respectively in the total emissions from agriculture in the form of CH_4 and N_2O. Emissions from both enteric fermentation and manure management have declined in comparison to previous years but the absolute volume continues to rise every year. The volume of these emissions is directly related to the health of an animal, proper functioning of their digestive tract, age, and weight. The nutrient content, quality and quantity of feed consumed, along with the genetic makeup of the animal, also plays a major role in the volume of these emissions.

Amul, which is India's largest dairy in terms of milk procurement and processing, also holds a rank in the global top 20 dairies. A 2020 study by the Institute for Agriculture and Trade Policy showed that Amul India recorded the largest increase in emissions due to the massive increase in milk production between the observed period (2015-2017). GHG emissions increased by 43% in 2017 to reach 45.1 MMT in CO_2-equivalent, making it the company with second largest emissions in the list. Among the top 13 dairies, Amul had a share of 5.4% in total annual milk intake and a notably high share of GHG emissions (13.4%) (Sharma, 2020).

Figure 7: Milk intake and GHG emissions of top dairies in the world



Source: Sharma (2020)

Surging emissions are expected to continue to rise in the coming years as the dairy herd continues to grow. Patra (2014) has projected that India's share of CH_4 emissions from enteric fermentation will grow from 15.1% in the global CH_4 emissions in 2010 to 15.7% by 2050. Similarly, India's CH_4 emissions from manure management are expected to increase from 13.5% in 2010, to 14.9% in 2050. All Indian dairy companies, including cooperatives, should take action to curtail emissions from livestock by offering preventive support to the farmers.

5 Overcoming challenges by adopting new innovations and technologies

Over the last few years, many cooperatives and private companies have started making use of cost-efficient technologies, which provide yield-enhancing and practical solutions tailored to the needs of the industry. Technologies such as artificial insemination using frozen straws date back to the 1940s, and these were widely used across the country during OF to enhance the productivity of animals. Similarly, the use of concentrates and silage for feed and fodder has been long used to meet the supply deficit. Many new technologies have been introduced and even the existing technologies have become more advanced and oriented towards solving the current challenges faced by the industry. Despite the growth, there is still room for existing technologies to ramp up R&D, extension and delivery stations to transform the dairy sector into a vibrant, competitive and more remunerative sector for farmers (Gulati and Juneja, 2021).

5.1 Green fodder hydroponics

Improving availability of green fodder in the country has immense potential to improve milk yields and improve the digestion process of cows and buffaloes, which also helps in curtailing GHG emissions. Green fodder provides the right amount of total digestible nutrients and crude protein and accounts for only 13-35% of the total cost of feed (Ramteke et al., 2019). Given the current shortage and high demand, the share of cost of green fodder is likely to increase in the coming years, adding to the total cost of milk production for the farmer.

Green Fodder Hydroponics is one of the most encouraging innovations in India to overcome the gap between demand and supply of green fodder without placing pressure on existing land resources. Hydroponics is a method of growing plants in a water-based solution without soil to produce quick and nutrient-rich fodder (Bakshi et al., 2017). Green Fodder Hydroponics requires control of external environmental factors such as light intensity and duration, temperature, humidity, pH of the solution/medium and mineral nutrients (Pandey et al., 2009). It includes a systematic set-up of shelves on which clean plastic plates are stacked with a layer of seeds spread over the tray. Seeds are kept moist with the help of spray irrigation to minimize the amount of water utilized, and excess moisture is drained out through holes in the trays. The majority of the seeds sprout within 12 hours of soaking and turn into an 8-9-inch-high grass mat in a maximum of seven days (Singh et al., 2015).

Fodder varieties like maize, barley, oats, sorghum, rye, alfalfa, horse gram, millet and triticale can be produced using this technology and they are highly palatable, digestible and nutritious for animals (Shit, 2019). It is one of the best alternative technologies in regions where conventional green fodder production is limited due to agro-climatic conditions (Naik et al., 2015). Some of the benefits associated with Green Fodder Hydroponics are efficient water management, year-round availability of fodder and adequate availability of nutritional feed and fodder for the dairy herd.

Hydrogreens, a Bengaluru-based agri-tech startup founded in 2019, has designed “Kambala”, a hydroponic fodder production unit (ICAR, 2017). The company has created a micro-climate cell fog forming machine which allows dairy farmers to grow fresh green fodder all year round. The device can be easily assembled, operated and managed, and can grow up to 20 kilograms of fodder with less than

5 liters of water per day. Each unit costs USD 426 and generates an electricity bill of less than USD 1 in a year. The company has recently commissioned a solar-powered version of the unit, which is priced at USD 639.2. Hydrogreens has installed around 130 Kambala units across the country and benefited hundreds of farmers (ICAR, 2017).

In 2018, Maharashtra-based Prabhat Dairy Ltd. educated farmers associated with them about hydroponic techniques for growing fodder and boosting milk yields. They encouraged women's self-help groups (Prabhat Sakhis) to kick-start a milk collection center and commence dairy farming using techniques like hydroponics to strengthen their prospects. The company had a Fodder Management Program which assisted over 300 cowsheds in drought affected area of Maharashtra through the hydroponics method of farming (Ghaswalla, 2018).

5.2 Napier grass: Leveraging biotechnology to improve generic feed and fodder

Use of biotechnology to improve feed and fodder crops has become very popular in India by utilizing genetic engineering for introducing foreign genes from unrelated species to improve the generic variety in terms of physical appearance, nutrients, yield and growing conditions (Kapoor et al., 2018). A cross between Bajra and Napier, popularly known as the Hybrid Napier, is a popular genetic improvement for fodder grass in India. It is made from an in-vitro rooting method which requires the stem cuttings/roots to be prepared in a controlled environment (ICAR, 2012). The first attempt to cross Bajra with Napier was made in 1953 to improve the yield potential and texture of leaves of the generic Napier (Biradar et al., 2020). Over the years, many varieties/crossbreeds have been developed by organizations such as the Indian Agricultural Research Institute (IARI), the Indian Grassland and Fodder Research Institute (IGFRI) and the Tamil Nadu Agricultural University (TNAU).

Hybrids have the biotic and abiotic capacity to adapt to climatic conditions across India and can be grown in saline soils, wastelands and terraces. They thrive well under an arid and semi-arid region. The hybrid Napier can tolerate moderate drought, as the root system is intense and ideal for cultivating along the water channels (Rathod and Dixit, 2019). It can be retained in the field for at least two to three years once planted and at least six to eight cuts are possible annually. If in excess, the fodder can be chaffed and converted to silage along with legume fodder in the ratio of 1:2 to serve as a source of crude protein throughout the year. In 2019-2020, HAP supplied 3.5 million cuttings of Co-4, Co-5, and "Pakchong 1 Super Napier" (hybrid from Thailand), which are improved varieties of Napier, to selected dairy farmers associated with them. The company also started developing food seeds which were supplied through its field staff to different dairy farmers. The company offers vitamin feed with cottonseed oilcake, soybean meal, de-oiled rice bran, maize and cane molasses under the name "Santosa". The feed is sold exclusively in the Hatsun milk banks and it is ensured that it is sold only at a small profit margin.

5.3 Tackling low genetic potential through assisted reproductive technology

One of the best ways to enhance the ability of the dairy herd in India is crossbreeding between indigenous breeds and exotic breeds imported from other countries. Artificial insemination is one of the most efficient reproductive biotechnologies used across India to improve the breed of the dairy herd (Choudhary et al., 2016). It was first introduced in the early 1940s in the barns of Maharaja of Mysore and the technology has evolved several times since then (Rath et al., 2016).

The recent development of sexed semen technology in India has increased the population of the female dairy herd in the country, as it increases the chances of conceiving a female calf and improves the genetic makeup of the dairy herd through crossbreeding. The female cattle population has increased by 18% in 2019 and the male population has declined by 30.2%. A similar trend was seen in the buffalo population where the female population increased by 8.6% and the male population declined by 42.3% over the previous census (DoAHD&F, 2020).

Sexed semen technology is one of the most pragmatic and easy ways to predetermine the sex of the offspring and make reproduction of genetically improved high-milk-producing females faster, along with reducing the cost of rearing male calves (Gulati and Juneja, 2021). Without assistance, the probability of conceiving a female offspring stands at 45%. When sexed semen is used for AI and after conception, there is a 90% chance that a female calf will be a progeny (Mohteshamuddin, 2017). The technology was originally patented by the US-based XY Inc., which was later acquired by Sexing Technologies headquartered in Navasota, Texas. In India, Sexed Sorting was introduced by Paschim Banga Go-Sampad Bikash Sanstha*,* Government of West Bengal in 2009. The organization established a Becton Dickinson (BD) Influx cell sorter laboratory under Rashtriya Krishi Vikas Yojana (RKVY).

Genus Breeding India (ABS India) was one of the first private and global companies to venture into India to provide consultancy on bovine genetics. It is a part of Genus PLC, which is established in about 80 countries around the globe as the leading provider of bovine genetics and reproduction services. ABS India started its first bovine semen sexing lab in the country at its Brahma Genetics Facility, Chitale Genus ABS India Private Limited, near Pune in Maharashtra, back in 2017 (Genus Breeding India, 2021). It was the only company with the technology to provide sexed genetics for breeds such as Holstein, Jerseys, indigenous breeds (Sahiwal, Red Sindhi Gir), crossbreeds and buffaloes (Murrah and Mehsana). They have further upgraded their technology and launched it under the name “Genus IntelliGen” technology which develops sexed bovine genetics without exposing the cells to high pressure, electric currents and shear forces. The company has also assisted the government by offering sexed sorted semen straws to farmers of Maharashtra. The straws are being offered at a subsided rate of USD 1.09 per straw in-comparison to the market value of USD 16.18 per straw (Biswas, 2021).

BAIF Development Research Foundation, a professionally-managed non-profit Public Trust, started its first sex-sorted semen production lab in 2018. The company provides quality sexed sorted semen from exotic/indigenous cow and buffalo breeds to farmers in the rural areas. The organization runs a “BAIF Cattle Development Program” under which more than 150,000 inseminations done used sorted semen with a conception rate of 44.3% and 90% female births (BAIF Bov Gen, 2020).

In vitro fertilization (IVF) is an Assisted Reproductive Technology that multiplies superior female germplasm faster (NDDB, 2021) and can provide 30 calves in a year from a cow or buffalo. IVF relies on the extraction of an unfertilized egg from the ovary of the donor female, which is matured under in vitro conditions, i.e. inside the laboratory instead of in a womb/uterus. All advanced dairy nations promote the technology, as it assists in the propagation of elite animals which produces high genetic merit bulls (DoAHD&F, 2020). The first female calf using Ovum Pick-up and In Vitro Embryo Production (OPU-IVEP) was created by the National Dairy Research Institute (NDRI), Karnal, in 2012 and the female calf was of the Sahiwal breed and named “Holi” (Saini et al., 2015).

JK BovaGenix (an initiative of JK Trust) started operations in March 2016 to rapidly propagate superior genetic merit. It was one of the first efforts to establish pregnancies from the IVF embryos of selected indigenous cow breeds. JK BovaGenix was one of the first NGOs to produce India's first IVF female calf from a frozen source on December 28, 2016, for the Tharparkar breed of Rajasthan. As of May 31, 2020, JK BovaGenix has produced 3,920 IVF embryos and provided IVF Services to 34 farms across the country. To date, 160 calves have been born using fresh IVF embryos, and 49 calves have been born using frozen IVF embryos (JKBovaGenix, 2020). JK BovaGenix were the first organization to produce 14 IVF calves from a single Gir Donor Cow named "Radha" in one year. In August 2020, the organization announced India's first batch of IVF buffalo calves, which were birthed on a buffalo farm located in the Pune district.

5.4 Management of dairy herd and supply chain monitoring

The majority of the technological adoptions in the dairy sector are driven by the need to manage value chains by farmers and processing companies through vertical coordination and spillover effects (Swinnen and Kuijpers, 2019). The perishable nature of milk and value-added milk products makes supply chain management more essential to ensure that the quality of milk is maintained from the farmer to the consumer. The dairy supply chain needs to be tightly knit with an efficient cooling mechanism and the ability to capture information at each node of the supply chain, from milk procurement to milk processing, to distributors, to retailer and the end consumers.

Raw milk procurement in India remains highly unorganized and fragmented, with limited technological information and traceability. The complexities of thousands of farmers pouring milk in a single bulk milk cooler results in incompatible milk quality and composition. Bhardwaj et al. (2016) highlight the importance of traceability and information systems in the dairy sector, which help assist in meeting the high product quality, consistency and safety standards of the export market and increase global competitiveness. The Internet of Things (IoT) is one the upcoming technologies in the dairy industry, which can improve the traceability of the dairy supply chain with the help of "smart cows" (Daum et al., 2022).

One of the most popular companies utilizing the IoT is Stellapps Technologies. Stellaps is using the technology to bridge the gaps in the dairy value chain by digitizing the production and supply of milk across the dairy supply chain. Their signature product includes "SmartMoo", an IoT router that acquires data via sensors embedded in milking systems, animal wearables, milk chilling equipment and milk procurement peripherals (Stellapps, 2021). The data is transferred from the application to a big data cloud service delivery platform, which is then collected and further analyzed. Their trade service includes what they call their "mooON solution", which is comprised of a device and an app, which function like a "Fitbit" for cattle. The device can detect heat periods and health disorders based on their activities and resting behavior. The data is uploaded into an app, which functions as a herd management application that provides recommendations to optimize herd performance.

Stellapps is connected to 11.5 million liters of milk every day and impacting 2.6 million farmers and 1 million cattle in roughly 35,000 villages in India. Many companies have deployed the IoT concept to strengthen their supply chain and increase the traceability of milk. Country Delight, HAP, and Thirumala are a few private companies that have adopted these solutions and reportedly achieved positive operational results.

Promethean Power Systems is another leading tech company which designs and manufactures refrigeration systems for cold-storage and milk chilling applications. It mainly targets off-grid and partially electrified areas in India and other developing countries. Their goal is to enable village-level chilling and have a positive impact on quality and costs with dairy processors by saving on running and maintenance costs of the equipment and eliminating the need for a diesel generator. Their cold storage and chilling applications reduce temperature of milk from 35 degrees Celsius to 4 degrees Celsius within seconds and have much lower maintenance costs. The company has established over 1,200 units and chilled 700 million liters of milk. It has assisted over 60,000 farmers by saving costs on diesel and electricity (Promethean Power Systems, 2022).

5.5 Ration balancing: A strategy to reduce costs and emissions

The quantity and quality of feed and fodder offered to dairy cows and buffaloes are less than the adequate requirements in India, which results in imbalances in the digestive system, sub-optimal milk production and overall health issues. The imbalances due to lack of adequate nutrition also increase the CH_4 emission per kg of milk by affecting the enteric fermentation process and chemical composition of the dung. One of the most cost effective CH_4 mitigation strategies for developing countries like India is to offer nutritionally balanced feeds (Hristov et al., 2013). Feeding ration-balanced high-quality forages, with special emphasis on changing carbohydrate composition is considered to be an immediate and sustainable methane mitigation approach of enteric CH_4 emitted from ruminant livestock (Haque, 2018). The amount of protein, energy and minerals in ration-balanced feed generally vary according to the age, breed and category of the cows and buffalo which need to be fed (NDDB, 2016).

A government Ration Balancing Program was implemented across 100 villages in Uttar Pradesh, which managed to reduce the cost of feed per kg of milk by 9.5% (MoEFCC, 2018) and the emissions level by 0.28 MT CO_2-equivalent between 2014 to 2016. In addition, a reduction in emission levels by 3.86 MT CO_2-equivalent was observed during the same period by feeding bypass proteins. A study conducted by NDDB on 37 early lactating buffaloes in two villages of Gujarat observed that ration-balancing reduced the average emission by about 15.21% in buffaloes (NDDB, 2016).

The Information Network on Animal Productivity and Health (INAPH) developed by NDDB aims to balance the diets of 2.4 million heads of Indian dairy animals to ensure increased milk output and reduced CH_4 emissions (INAPH, n.d.). The application has a module on nutrition, which provides the least cost ration-balanced formula based on the profile of the dairy herd and availability of feeds and fodder. Several private companies offer compound and balanced feed depending on the age and lactating stage of the animal. National Institute of Animal Nutrition and Physiology (NIANP) recently came out with “Harit Dhara” and “Tamarin Plus” as an attempt to curtail CH_4 emissions. These supplements are made from tannins and saponins which have high natural phyto-sources and can reduce CH_4 emissions from enteric fermentation by 20% when livestock are given appropriate doses (NIANP, 2021).

Godrej Agrovet Limited (GAVL), one of the leading animal feed producing companies in India, focusses on providing Indian farmers with cost-effective solutions and animal feed to help improve productivity. Animal feed was the largest source of revenue for GAVL in 2021, with a share of 43% of the total revenue (GAVL, 2021). The company has 32 manufacturing plants which produce over a million metric tons of animal feed every year. Their dairy feed contains proteins, energy, minerals and vitamins to meet the nutritional requirements of the herd, depending on their category and age group. Currently, the company also offers calf starter, calf grower, heifer feed and lactation feed varieties, among others.

5.6 Utilizing dairy emissions to generate electricity

Cows and buffaloes are significant sources of CH_4 emissions from the enteric fermentation of the animals and mismanagement of dairy herd manure. While emissions arising out of enteric fermentation can be balanced by feeding recommended amounts of fiber and a generally healthy diet, India has considerable potential to process manure more efficiently. Using manure as a source of energy is common in developing countries, as in most rural households biomass-like manure is the primary source of energy. The manure is dried and formed into “dung cakes” which are used as a burning fuel to heat traditional earthen ovens (Raj, 2014). There exists a growing market for utilizing the cattle and buffalo manure and producing sustainable energy from it. There is a need to efficiently harness a large amount of manure, keeping in mind the quantum of green energy it can provide.

India can treat and manage the manure at an aggregate level, as cow and buffalo manure are ideal biogas sources (Clausen, 1979). According to the Ministry of New and Renewable Energy (MoNRE), India has the potential to create 18 billion cubic meters of biogas annually (MoNRE, 2014). The biogas can generate electricity for the rural areas in the country where delivery of conventional sources of energy is difficult due to infrastructural constraints (Bhattacharyya, 2006). Biogas is a renewable source of energy and requires economic and straightforward techniques to produce energy and electricity. The total potential of renewable power generation in India on March 31, 2020, was estimated at 1,097,465 MW, out of which biomass power had a share of 1.6% (MoSPI, 2021). Interactive biopower plants had an installed grid capacity of 9778.31 MW and 5,060,042 off-grid biogas plants existed in the country (MoSPI, 2021).

Biopower plants use a technique called Anaerobic Digestion to convert the energy stored in manure into biogas plants which are then utilized to generate electricity. Anaerobic Digestion provides optimal conditions for the methane-producing bacteria to thrive. A typical biogas plant consists of a collection center, anaerobic container, effluent storage and handling, and gas handling and utilization chambers. The rate of manure in conversion depends on the consistency of the manure, characteristics of the manure and the environment of the digestor (Liebrand and Ling, 2009). Biogas generated out of Anaerobic Digestion roughly consists of about 50-75% CH_4, 25-50% CO_2 and very small quantities of gases, such as H_2 sulfide and ammonia (Surendra et al., 2014).

In 2018, the Government of India launched a "National Biogas and Organic Manure Program" (NNBOMP) to establish small Biogas Plants in size range varying from 1 m^3 to 25 m^3 (MoNRE, 2021). The program’s objective is to offer green and clean renewable gaseous fuel for cooking, lighting and small power needs of the potential farmers and dairy farmers. Under the program, five million biogas plants have been installed as of March 31, 2020. A Galvanizing Organic Bio-Agro Resources Dhan (GOBAR-DHAN) scheme was implemented under the Swachh Bharat Mission Gramin-Phase 2 in 2018, which focused on processing dung into biogas and organic manure leading to the generation of opportunities for employment and household savings (MoDWS, 2018).

Sistema.bio, which provides biogas converters to small-scale farmers, is one the most notable upcoming private ventures. The company first marked its presence in India through a CINI project, an initiative of TATA trust. They installed 60 biogas facilities in Gujarat, which provided biogas and bio slurry to over 560 people. One year later, the company incorporated in India and installed 500 units in the first year of operation. In collaboration with other companies such as TATA Trust, NDDB, Shell Foundation, Dairy Mate and Madhusudan Dairy, Sistema.bio is emerging as a major player in India's biogas sector.

6 Concluding remarks

India's milk production has accelerated at an average annual growth rate of 5.6% between FY 2013 and FY 2022, backed by institutional engineering and cost-effective innovations. Historically, however, OF can be seen the flag bearer for revolutionizing the dairy industry during the 1970s through 1990s and transforming India from a milk deficient nation into the world's largest milk producer. Throughout this period, organized private dairy companies were also procuring milk and expanding their processing capacity. But the expansion truly gained momentum in the wake of the complete de-licensing of the dairy industry in 2002-2003.

It is notable that private dairy companies have managed to build a procuring and processing infrastructure competitive to the dairy cooperatives over the years. However, the policy environment in the Indian dairy sector has always been skewed towards the cooperatives. In many instances, the government has given preferential treatment to dairy cooperatives in the form of aid, incentives and subsidies. For instance, the Karnataka's dairy cooperative offers an incentive of USD 0.07 to USD 0.08 per liter of milk above the procurement prices to the farmers. The cooperative receives this support from the state government as an incentive for farmers, which distorts pricing by artificially inflating the procurement prices. The subsidy puts unnecessary pressure on private dairy companies to compete with the high procurement prices and squeezes profit margins. Such preferential policies distort market dynamics and lead to a "crowding out" of private companies. There is an urgent need to create a level playing field where both dairy cooperatives and private companies can formulate a fair price discovery system and offer remunerative prices to farmers without any external aid from the government.

The largest milk producing state in India is Uttar Pradesh, which has one of the lowest milk procurements by state dairy cooperatives. The majority of the milk is handled by the unorganized sector or the organized private sector in Uttar Pradesh which can process between 0.5 – 1.0 MLPD of milk – significantly more than the procurement of cooperatives across the state. Similarly, private companies like Hatsun Agro Foods, Parag Milk Foods, Heritage Foods Ltd and Dodla Dairy Ltd had daily milk procurement exceeding that of state cooperatives. There is an absence of comprehensive and reliable data on milk procurement and processing capacity of private dairy companies and the actual capacity of these companies. Lack of data presents a challenge for developing suitable policies to offer financial and infrastructural assistance and further boost growth.

India's milk production has experienced a strong push from different innovations which were tailored to tackle the problem of low productivity due to stunted genes and lack of fodder. Adoption of new technologies and innovations has turned out to be imperative for dairies across the country to sustain their operations. As new technologies and innovations mushroom at different stages of the dairy value chain, management of dairy farms and animals has become much easier. Furthermore, integration of the IoT in managing the value chain has helped in the collection of data and adoption of tools, which can be leveraged to improve sustainability.

There is a need to ramp-up the delivery system of these innovations and ensure that they are accessible to farmers, even in remote areas of the country. In addition, it is crucial to make farmers aware of the benefits of these innovations and how they would play a role in increasing a farmers' income from milk production. There is still room for existing technologies to help ramp up R&D, agriculture extension and delivery stations to transform the dairy sector into a vibrant, competitive and more remunerative sector for farmers (Gulati and Juneja, 2021). It is expected that the demand for cost-efficient technologies will also increase in the coming years, opening doors to investments and new "dairyprenuers". With the infusion of these technologies – from hydroponics to overcome the shortage of green fodder to sex sorting semen to improve genetics and increase the number of females – the best of Indian dairy sector is yet to come.

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Development Research
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Working Paper Series

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Photo: Heike Baumüller

Published by:
Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Genscherallee 3
D – 53113 Bonn
Germany

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