final report

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Development of the National Livestock Methane Database

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Executive summary

The National Livestock Methane Database was created to provide a single, searchable, publically accessible repository for information generated in the Reducing Emissions from Livestock Research Program (RELRP) and National Livestock Methane Program (NLMP); two programs co-ordinated by MLA. The research was funded by the Commonwealth of Australia with co-funding from MLA, Dairy Australia, Australian Wool Innovation and research partners. Additionally, research funded through the CSIRO Livestock Methane Research Cluster and the Commonwealth Filling the Research Gap round 2 program were also selected for inclusion in the database.

Research conducted under the auspices of these programs is valued at approximately AU$40 million. The impact of this research for the industry cannot be maximized without an effective mechanism to make the data available to the research community and to extend the findings to industry. This database is intended to achieve these goals.

The research program sought to bring together domain expertise in the fields of database creation and development and ruminant nutrition, specifically around enteric methane emissions and their mitigation. A steering committee comprised of policy, extension, research and education representatives assisted in defining the terms of reference for the project. Throughout the project the project team met with research groups involved in NLMP both electronically and face to face. Database presentations were given at NLMP science updates and steering committee meetings Three focus meetings were held to discuss and demonstrate the database. The database was launched at the final NLMP technical workshop and update to government held in Ellinbank on 9th to 11th June 2015.

Following preliminary iterations of the database design using data from RELRP, it was decided to adopt a proprietary database system that met the criteria needed for this project. This reduced the cost of the original milestones and a four month extension was granted to 32st October 2015. Based on feedback from the Department of Agriculture an additional milestone was included to service the desire to mirror the research database with a database more aligned to the needs of the producer and other non-technical groups. This was termed the producer button. As the NLMP program only ended in June 2015, a considerable proportion of data was not available to the database in June 2015. The four month extension also allowed for all the NLMP data to be uploaded.

Following feedback from potential users, it was decided to create a producer button which allowed the user the option of clicking on a technical representation of the database (researcher button) or a non-technical version (producer button). This was achieved by mirroring the original database, rebadging the headings and then editing the content accordingly. The remit of the current contract was to set up the producer button and provide enough content to demonstrate how it would be used. This has now been achieved and the next phase to be conducted under a following contract with University of Western Australia (UWA) will complete the uploading and editing of content for the producer button.

It was always the intent that the database would remain current, live and relevant after the completion of this project. This legacy has now been secured by the continuation of development under funds from the Rumen Pangenome program and managed by UWA. This contract will allow for the uploading of data from the Filling the Research Gap Round 2 projects. Some of these reside in the Rumen Pangenome program and a further three are administered directly by the Department of Agriculture. The UWA contract will also be responsible for completion of the producer button.

The legacy for the National Livestock Methane Database is that it get used and remains relevant and up to date. The project team have worked to develop a user-friendly product, but it is only as good as the content it contains. It is hoped that content continues to be added beyond the timeframe of the two research projects. UWA have tentatively committed to be the custodian of the database and it is hoped that a long term agreement can be negotiated.

Livestock methane emissions remain a significant proportion of the nation’s GHGs. The database represents the single most informative source of information on this topic in Australia. AS carbon accounting of one form or another becomes more widely adopted we believe the utility and influence of this database will continue to grow.

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1 Background

Australian agriculture is responsible for 16% of the nation's greenhouse gas (GHG) emissions, of which about 64% are as methane, produced largely by enteric fermentation in the rumen of cattle, sheep and other ruminants. Consequently in 2008-09 the Commonwealth Government initiated the Climate Change Research Program with an $11.3 million investment in the Reducing Emissions from Livestock Research Program (RELRP). This was followed by a second round of funding of $13.9 million under the National Livestock Methane Program (NLMP) as part of the Filling the Research Gap program from 2011-12 to June 2015. Concomitant with these programs CSIRO launched a $7 million research cluster and in 2012-13 a second round of Commonwealth funding was dedicated to the Rumen Pan Genome project. This level of investment in one area of research over a relatively short time was unprecedented in Australian livestock industries. The funding generated a high degree of collaboration between research entities and accelerated the rate of gain in our knowledge of the mechanisms, mitigation and management of enteric methane emissions. However there was no formal mechanism in place to capture the amassed information into a system that allowed for easy retrieval of information in a format useful for researchers, producers and the public at large.

The failure to capitalise on the knowledge base is attributed to a lack of awareness that the information exists, difficulties in data access and the inability to collate disparate dats streams for meta-analysis. There was some initial investment in improving access to experimental data generated as part of the RELRP through the development of the RELRP metadata catalogue and portal. This project aimed to build on that work to provide access to integrated livestock methane data. Webservice Technologies have now matured to the point to allow routine delivery of data, thus unlocking critical datasets for broader use. Through the development of data Webservices, data sources such as that from RELRP, NLMP, other MLA datasets and the CSIRO Livestock Methane Research Cluster can be unlocked and accessed easily by a range of tools and analytic systems. This allows for high level access and interpretation of data through modelling to better inform producers, land systems greenhouse gas accounting, agriculture policy and industry decisions.

The scope of this proposal was to deploy and configure a web service data infrastructure to unlock that data ensuring easy and on-going access as well as providing a platform for future delivery as needs change. Given the large investment in understanding livestock emissions, it became imperative to allow for ready analysis of this information to the fullest extent and ensure clear, comprehensive, and up to date information can conveyed to the policy makers, influencers and primary producers who, collectively, can reduce the carbon footprint of livestock.

The contract was awarded to a CSIRO team comprising a livestock methane domain specialist, a data analytics specialist and programmers. A consultant was awarded a sub contract to assist with data management. A variation to the original contract was made in June 2015 extending the end date to October 31st 2015 and including three new objectives.

2 Projective objectives

The following objectives were developed:

1. An integrating information system that consolidates data from MLA, RELRP, NLMP and Livestock Methane Research Cluster
2. Data model for storage (a database model) to optimise the on-going storage and integration of new datasets
3. Data model for data delivery (a public model) optimised for public delivery or sharing of data. This will be an XML based open standard format.
4. Platform on which to build capacity to mine the NLMP themes and apply analytics such as cross scale interactions and handling uncertainty
5. Capability to store and serve many different types of data including spatial, temporal, tabular and textual.
6. Capability to integrate new livestock methane data into the information system for access and analysis
7. NLMP datasets and final reports uploaded onto the database*
8. User buttons built to direct the user (e.g. researcher, producer) to context–relevant information within the database*
9. Upload of a limited amount of producer friendly livestock methane materials and preliminary testing of the user buttons*

3 Methodology

The project methodology followed an agile iterative methodology described in the Fig. 3.1 below. This methodology has become popular due to the better match of the delivered systems to the user needs. Our team was experienced in the application of this methodology for successful delivery of projects. A key aspect of this methodology is that after each iteration, feedback is obtained from the users that is then included in the updated requirements for the next iteration. This project delivered using three iterations:

1. **Proof of concept** – this iteration will test the initial database structures and components for suitability of integration and delivery of the data, as well as deploy the initial and proof of concept database system.
2. **Main Build** – Deliver an initial working system, suitable for testing and improvements. Engagement workshop will confirm the integration data model.
3. **Confirmation of Delivery –** Deliver the integrated data system to the final custodian. Preceded by a final update to the system and suitable training for the custodian.

During the main build, it became apparent that the whole process could be expedited by adopting a proprietary model known as CKAN. However the essential components of the project remained unchanged.

* Objectives 7 to 9 were added with the project variation extending the end date to October 31st 2015

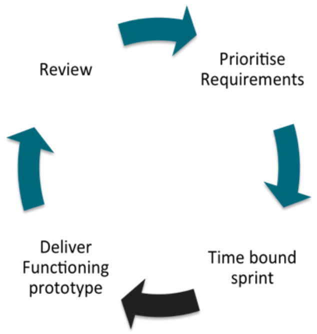


Fig. 3.1: Iterative Methodology

3.1 Proof of concept

The phasing of the project reflected the continual improvement philosophy of Agile Development. The first phase of the project delivered basic functionality of the system as well as defining the integrated data model for data storage. This data model was suitable for storing the integrated data and was to be optimised for efficient storage. Data integration also requires semantic integration. This requires that definitions of terms (or vocabularies) are harmonized. A first attempt at the harmonization of these vocabularies was undertaken during this phase.

The availability of datasets to the project, their formatting and consistency are key factors in determining how much data might be ingested into the integrated database during the project. However, experience in working with the full variety of available data was used to inform design and provide methods for further work in ingesting diverse data. Lastly, the Metadata Catalogue should be suitable for integration. This requires that the catalogue be conformant to a common profile or schema prior to integration. These tasks were scoped in the early stages of the project.

At the completion of phase 1 a workshop was held with project leaders to demonstrate how the database would work and to seek feedback from project leaders to improve the process.

3.2 Main build

During this phase of the project the main functionality of the system was developed. However as a result of advances in database systems the team opted to select an open source data management system. The Comprehensive Knowledge Archive Network (CKAN) is a web-based open source data management system for the storage and distribution of data, such as spreadsheets and the contents of databases. The system is used both as a public platform and by various governments, including the Australian and South Australian governments. The platform is designed to make a wide array of data formats readily useable. Being compatible with other systems it also makes federation of databases readily possible, thus allowing for searching across multiple databases.

This decision significantly reduced the developmental phase of the project and allowed for adaption of CKAN to suit the particular needs of the project. Rigorous testing and design iterations secured the adaptability of the database system for future requirements.

3.3 Confirmation and delivery

This phase was the final iteration of the project and delivered the final version of the integrated database system. It was intended that the transfer of the final product would be a "document free" process with the recipient receiving the "keys" to the program. All information pertaining to the database was to be provided in digital format as a component of the actual database. From the early stages of the project, it became clear that MLA was not in a position to maintain the database after the termination of the project. The project team has considered several options and funding formulae to ensure the database remains live and current. In order to secure this outcome, an extension to the original project was negotiated. During this extension, negotiations with University of Western Australia resulted in a commitment to secure a new contract with the University a process that is currently ongoing. Consequently database development will remain active beyond the scope of this contract. The main development will be full deployment of the producer database which was initiated as part of this contract.

This project will make utilized IT infrastructure in the cloud to facilitate easy and smooth transfer of the system to the final custodian. A suitable cloud provider was identified and infrastructure sourced to support the project. The project holds all datasets in a secure area. This deployment model allows the system to be fully tested and delivered without having to adjust and retest based on internal IT policies. In addition it reduces the need for capital investment, we want to avoid any capital expenditure for servers or similar. And as the system grows, more resources can be added easily as well as providing for easy connectivity to any analytical resources which might be required.

3.4 System architecture

In summary, with reference to the architecture figure (Fig 3.2) to integrate systems the following four components were compiled:

- Data holdings that are machine accessible
- Metadata catalogue
- Vocabulary of terms (glossary)
- Documented data models

We have used a traditional n-layered architectural diagram to describe the system components and how those components can be used to deliver integrated data to users through the portal.

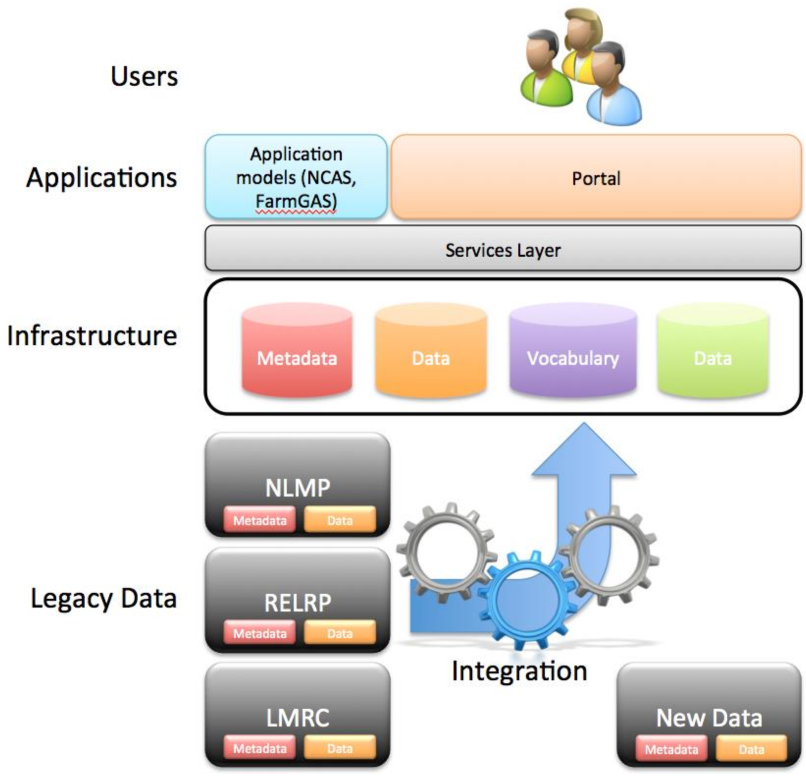


Fig. 3.2. System architecture

3.5 Project team and governance

The project team comprised of the following individuals:

- Ed Charmley, CSIRO, project co-ordination
- Peter Fitch, CSIRO, lead, database design team
- Julian Hill, Ternes Agricultural Consultancy, domain expert & database management
- Simon Cox, CSIRO, Database design
- Qifeng Bai, CSIRO, technical support.

The project governance structure (Fig 3.3) makes use of the NLMP Industry Advisory Group (IAG) from which a sub-committee was formed to act as a steering committee for the project. The committee comprised of Hutton Oddy (genetics and big data background), David Marland (extensions and policy), Phil Vercoe (animal scientist) and John Black (MLA representative and modelling expertise). The steering committee had oversight of the project providing advice and industry knowledge to ensure successful delivery and that user needs are met. The proposed governance model can be seen below.

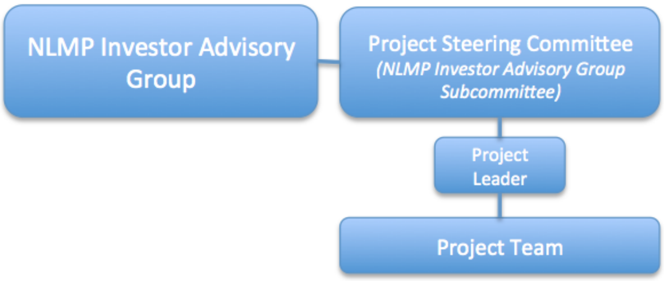


Fig. 3.3 Governance structure of the database.

4 Results

4.1 Programs and projects

The four programs that contributed to the database are shown in Figure 4.1. Filling the Research Gap round 2 is scheduled to end in June 2016. Five projects in The Rumen Pangenome program and a further 3 projects will be included in the database by June 2016.

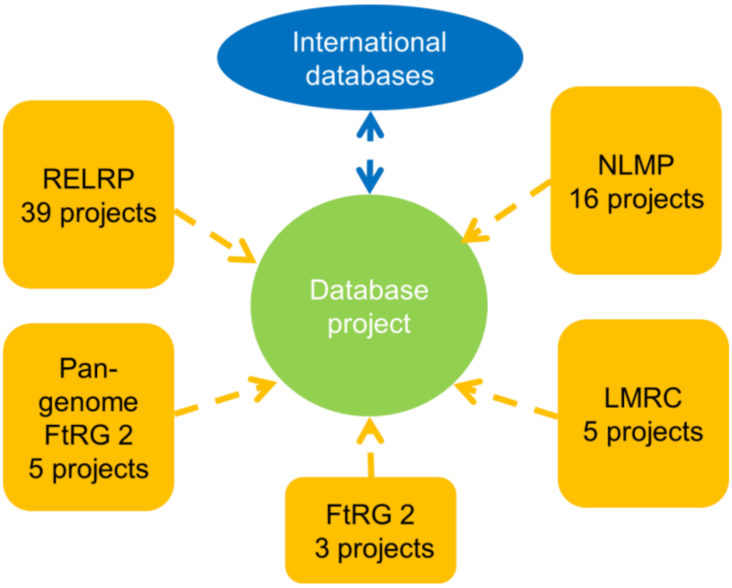


Figure 4.1 Sources of information for the database.

4.1.1 Reducing emissions from livestock research program

There were 39 projects completed under RELRP across 7 themes:

- Quantifying methane emissions
- Genetic approaches to reduce methane

- Feed supplements
- Feed additives
- Native and other forages
- Farming systems for lower methane emissions
- Managing emissions from feedlot waste.

A metadata catalogue and portal was developed to manage RELRP data and this was used to access metadata from RELRP for the current database. Further information was provided by MLA in the form of final reports for the 39 projects (Table 4.1).

Table 4.1. RELRP projects

Project title	Lead organization
Novel individual enteric methane measuring system for multiple ruminants	CSIRO
Metagenomic analysis of feed utilization and hydrogen balance in Australian livestock for lower methane emissions	CSIRO
Phylogenetic identification of rumen microbial organisms linked with significant differences in methane emissions	SARDI
Blood methane concentration as a marker for bovine greenhouse gas emissions	CSIRO
Effect of starch based concentrates with different degradation characteristics on methane emissions.	DPI Victoria
Archeaphage therapy to control rumen methanogens	University of Queensland
Rumen microbial profiling – a tool to investigate methane mitigation strategies	SARDI
Genetic improvement of beef cattle for greenhouse gas outcomes	NSW DPI
Methanotrophs in natural ecosystems and their role in ruminant methane mitigation	University of Queensland
Mitigation of methane emissions from the northern Australian beef herd	CSIRO
Manure management to reduce greenhouse gas emissions from cattle feedlots	University of Melbourne
Antimethanogenic bioactivity of Australian plants for grazing systems	University of Western Australia
Breeding low methane mitting sheep and elucidating the underlying biology	CRC for Sheep Industry Innovation
Use of peptide –phage display libraries to discover peptides that are bioactive against rumen methanogens	CSIRO
Increasing productivity and reducing methane emissions by supplementing feed	QDPI & University of

Project title	**Lead organization**
with dietary lipids	Queensland
A genomic strategy to identify archaeal viruses in the rumen	QDAFF
Enteric methane abatement strategies for ruminant production systems in south eastern Australia	DPI Victoria
Using infrared thermography as a proxy for measuring methane emissions	University of Melbourne
Mitigation of methane emissions from the northern Australian beef herd demonstrating field laser research	CSIRO
Demonstration projects for on-farm practical methane strategies	MLA
Can multiple short-term measures of methane be used to quantify daily methane emissions in beef cattle?	University of New England
Intra-ruminal measurement of methane validation and verification under different management systems	CSIRO
Variability in fermentability and methane production in lucerne	SARDI
Farming systems for lower methane emissions, demonstration and information delivery	MLA
Novel strategies for enteric methane abatement	University of New England

4.1.2 National Livestock Methane Program

The NLMP is comprised of sixteen projects across six themes, these being measurement of methane, genetics, supplements, forages, rumen microbiology and coordination (Table 4.2). Uploaded material comprises of final reports which replaced interim milestone reports and data files from individual experiments.

Table 4.2. NLMP projects

Project title	Lead org.
Measuring methane in the rumen under different production systems as a predictor of methane emissions	CSIRO
Development of gas selective membranes (for intra-ruminal capsules)	RMIT
Evaluating and optimisation of GreenFeed Emission Monitoring units for measuring methane emissions from sheep and cattle	UNE
Genetic technologies to reduce methane emissions from Australian beef cattle	NSW DPI
Understanding methane reducing tannins in enteric fermentation using grape marc as a model tannin source	AWRI
Development of algae based functional foods for reducing enteric methane emissions from cattle	CSIRO
Supplementation with tea saponins and statins to reduce methane emissions from ruminants	CSIRO
Practical and sustainable considerations for the mitigation of methane emissions in the northern Australian beef herd using nitrate supplements	Ridley
Strategic science to develop dietary nitrate and defaunation as mitigation methodologies for grazing ruminants	UNE
Enteric methane mitigation strategies through manipulation of feeding systems for ruminant production in Southern Australia	DPI VIC
Impacts of *Leucanea spp*. plantations on greenhouse gas emissions and carbon sequestration in Northern Australian cattle production systems	CSIRO
Best choice shrub and inter-row species for reducing emissions and emissions intensity	UWA
The mechanism of antimethanogenic effects of bioactive plants and products on methane production in the rumen	UWA
Efficient Livestock and Low Emissions (ELLE) from southern grazing systems	UWA
Culture-independent metagenomic approaches for understanding the functional metabolic potential of methanogen communities in ruminant livestock	CSIRO
Comparative analyses of rumen microbiomes to mitigate ruminant methane and improve feed utilisation	CSIRO

4.1.3 Livestock Methane Research Cluster

The cluster involved participation from the following research establishments:

- University of Melbourne (lead organization)
- University of Western Australia
- University of New England
- Macquarie University
- Royal Melbourne Institute of Technology
- University of Wollongong
- Agriculture and Agrifood Canada & University of Alberta
- CSIRO (collaborator)

The research program was arranged according to Figure 4.2 across three scales; laboratory, animal, landscape. As the final report comprised a synthesise of all research studies conducted under the program, the cluster is represented by the final report on the database.

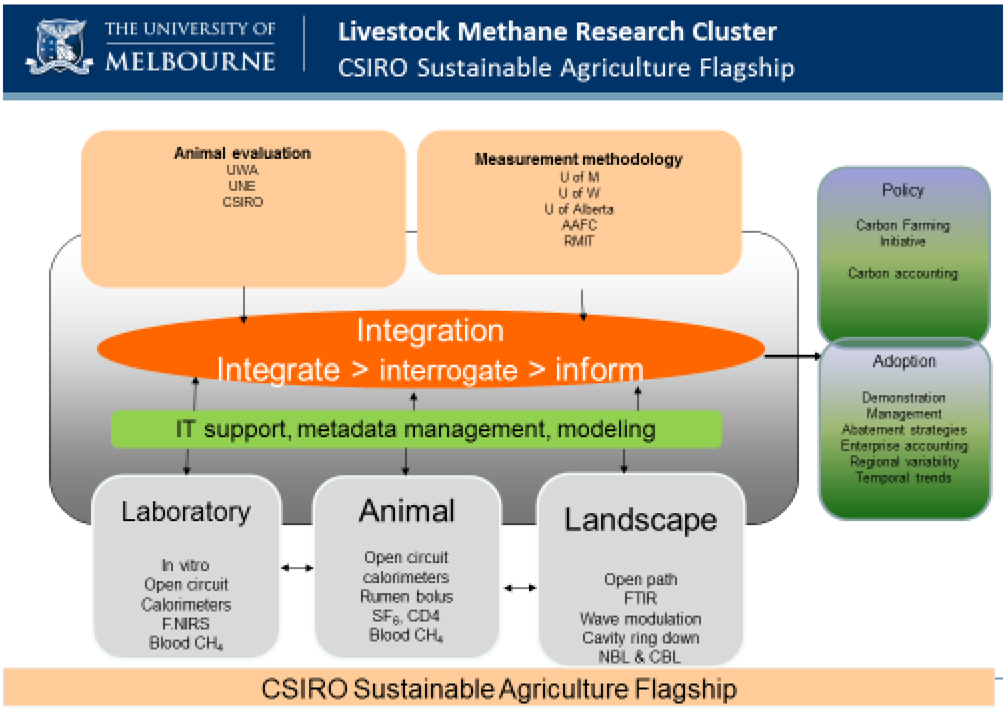


Figure 4.2. Arrangement of projects within the Livestock Methane Research Cluster.

4.1.4 Rumen pangenome project

The objective of the RPP is to provide high level coordination across the RPP network of projects to reduce enteric livestock methane emissions in Australian livestock under Round 2 of Filling the Research Gap program. Research projects that form the RPP will address the following research priorities under Round 2 of Filling the Research Gap program:

Research priority 1: Reducing methane emissions from livestock production systems
Research priority 6: International collaboration

The RPP will build on work undertaken through the Reducing Emissions from Livestock Program and the National Livestock Methane Program. The RPP will integrate research and development activities across all research providers including CSIRO, universities and collaborating national and international research organization partners. The RPP will synthesize research findings to develop understanding about:

Host control of methane emissions from sheep

Genetics to reduce methane emissions from Australian Sheep

The trade-offs between feed use efficiency, methane and reproduction in sheep

Maximizing energy yielding rumen pathways in response to methane inhibition

All projects under the RPP cooperate in order for the functions of the Program Leader to be fulfilled. Additional oversight for the strategic direction of the RPP is provided by an Investor Advisory Group (IAG), comprising a representative from each of the Commonwealth, Industry stakeholders (Meat and Livestock Australia Ltd, Dairy Australia Ltd where appropriate), and consortium partners including representatives from AgResearch NZ, The Pastoral Greenhouse Gas Research Consortium (PgGRC), European Union (EU) Ruminomics & International Sheep Genomics Consortium. The RPP draws on existing knowledge (conducted in the Reducing Emissions from Livestock Research Program (RELRP) and the National Livestock Methane Program (NLMP)) and new knowledge developed over the life of the program of work and beyond. The consortium provides a platform for technical and scientific exchange through national and international facilitation of meetings to ensure Priorities 1 and 6 are fulfilled. This includes reporting to NLMP and the National Agricultural Manure Management Program (NAMMP). KPI's will be set for program performance in all embedded research projects using milestones that are directly linked to the delivery and achievement of outputs within (RPP) and between (NLMP) programs.

Outcome 1. Effective coordination of the Rumen Pangenome Project ensuring delivery of all outputs to investors and stakeholders.

New knowledge developed through Australian government funded programs will be communicated to the Global Research Alliance (GRA) through the Livestock Research Group, fulfilling an objective of the Australian government for participation in GRA activities.

Outcome 2. New knowledge communicated to Global Research Alliance through the various facilitating groups thereby ensuring Australian government and research participation.

New knowledge will be shared between networks outside of GRA activities but closely aligned to those activities (for example EU Ruminomics). Representation of these networks and international partners is essential on the proposed steering committee of the RPP to facilitate national and international exchange.

Outcome 3. New knowledge communicated to closely affiliated research networks to the Global Research Alliance through the various participatory activities thereby ensuring Australian government and research participation.

The RPP will promote collaboration between researchers and industry members resulting in synergies between projects under the NLMP and RPP. This will include communication across projects under Filling the Research Gap and the associated Carbon Farming Futures programs, Action on the Ground and Extension and Outreach.

4.2 Uploading the data

Data takes many forms, from visual images to very large data files. CKAN can accommodate most forms of data. However, for consistency and ease of use there are certain rules that have to be applied. This is a particularly important for retrieval of information form the database and interpretation of what has been retrieved. The database has a structure that has to be adhered to when setting up the upload framework and preparing the data for uploading (See file: Template for uploading.xls). The database uses a hierarchical structure as outlined below (Fig 4.3):

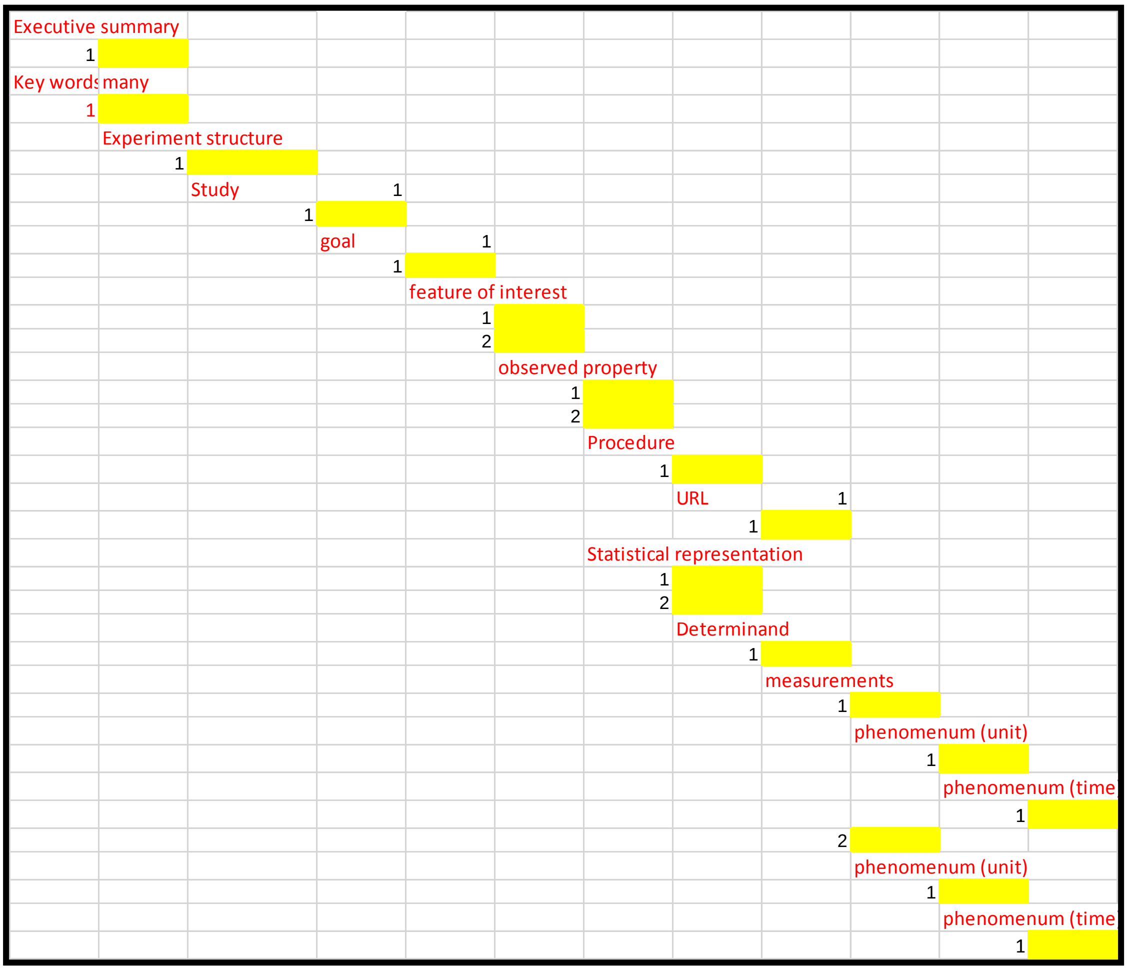


Fig 4.3. Example of the hierarchical structure of the database

Uploading requires an understanding of the meaning of the various hierarchy levels and for this reason templates for each project were built by the project team. Once the structure has been established the actual uploading of information is relatively straight forward. However it is essential that excel datafiles are formatted using a consistent methodology and each data file has to be associated with a metadata file that explains in detail the meaning of the data, the units used, and pertinent information about the specific conditions of the study from which the data is derived (See file "example of metadata"). The need for consistency among various projects and the difficulty in getting a large number of individuals to adopt a standardized approach to their data was causing consternation among project leaders and leading to delay in data delivery. For this reason, it was agreed that the database team would screen, standardize and upload the data on behalf of the project leaders.

4.3 Using the database

The database can be accessed at HTTP://ckan.cloudapp.net. Upon login the user is provided with a "welcome to NLMP" home page. This includes a brief introduction and the option to click on a "Producer" or "Researcher" version of the database (Fig. 4.4).

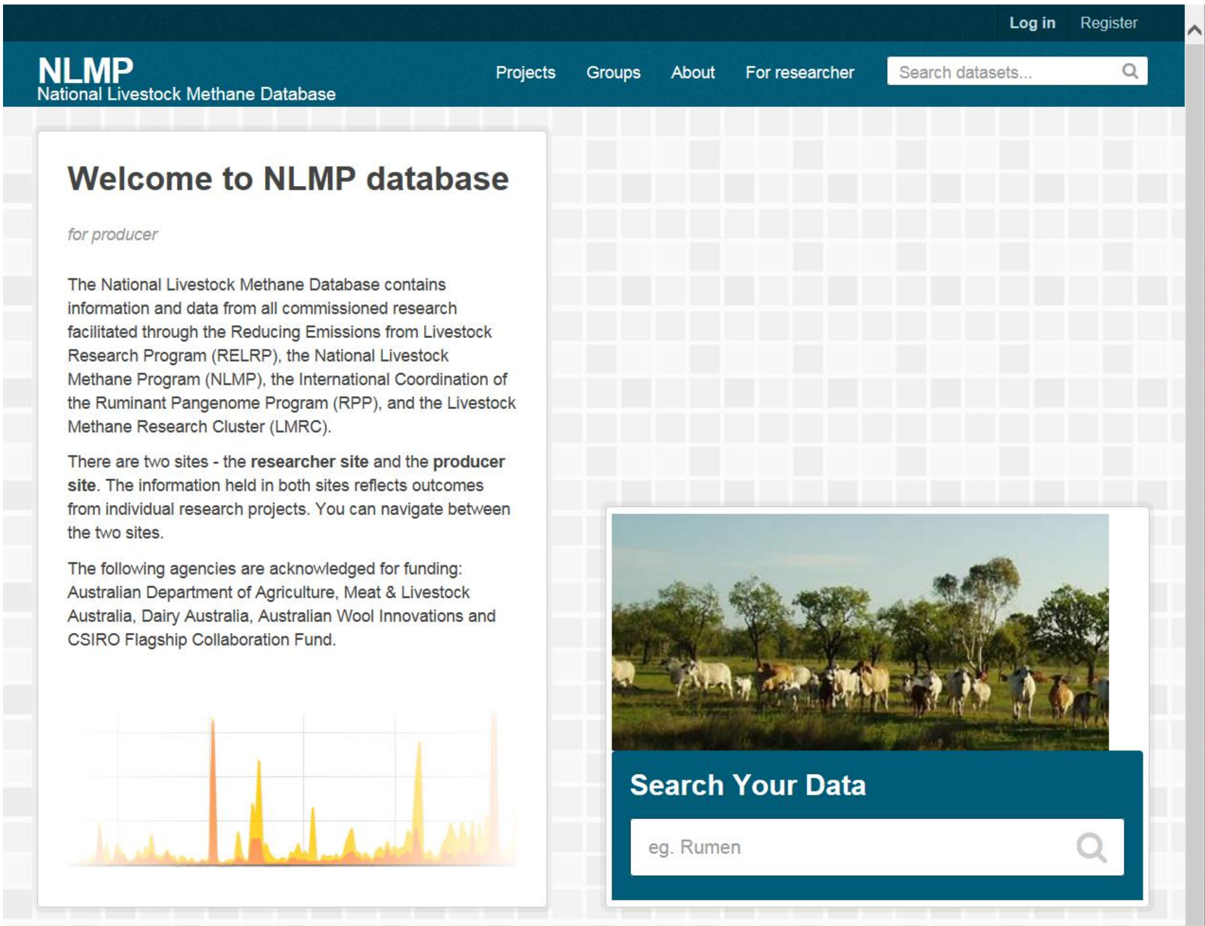


Fig. 4.4. CKAN home page –displaying the producer side of the database

The CKAN architecture has been modified to allow the two sides of the database to be viewed separately but the user can readily switch from one sire to the other (Fig. 4.5). To achieve this the three original levels in CKAN have been re-allocated. The highets level now refers to the Producer or Researcher versions of the database. The next level refers to organizations (e.g. AbacusBio) and the final level refers to projects in the Researcher version and Groups in the Producer verison. The previous experiment level is now fully operable from within the Projects level in the Researcher version. For the Producer version, levels are currently being redefined according to Figure 4.5

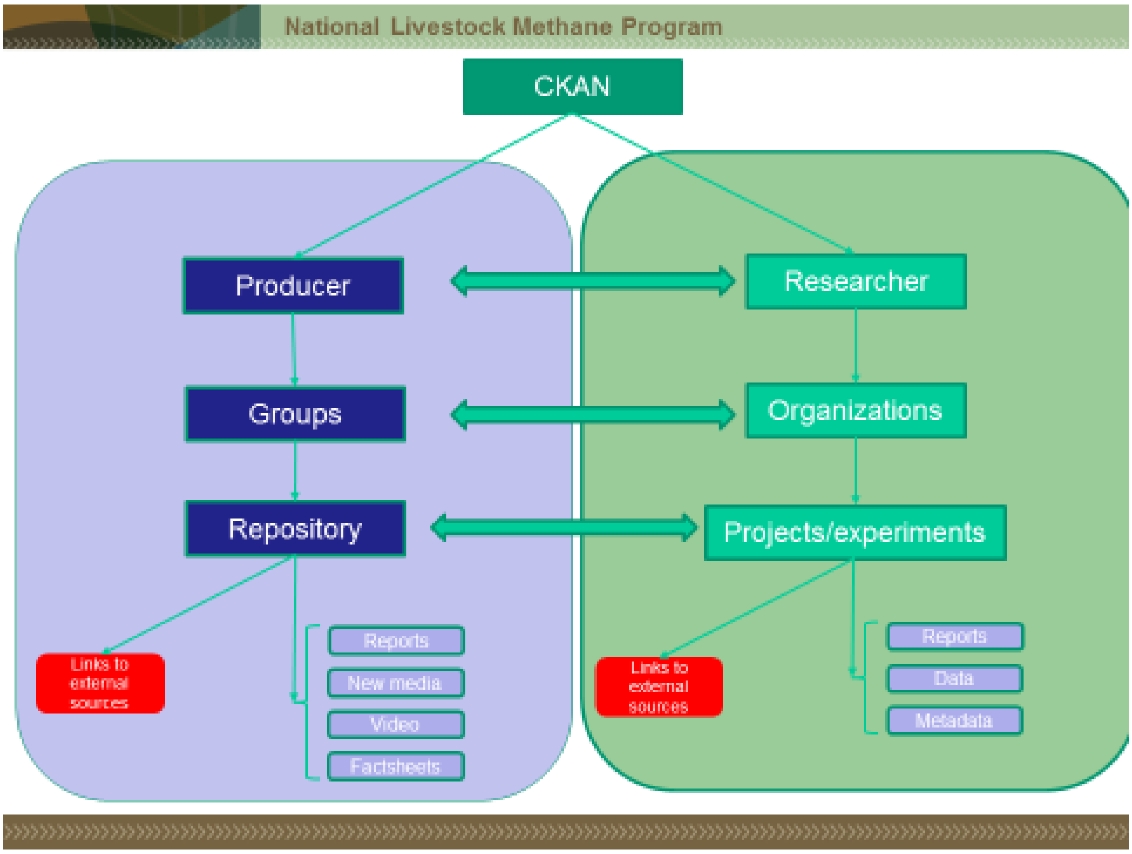


Figure 4.5. Architecture for the splitting of CKAN between "Researcher" and "Producer" buttons.

4.3.1 The Researcher button

The "Researcher" button transfers the user to further information arranged as organizations and projects. These last two buttons refer to the CKAN architecture and data can be accessed from both levels. Data uploads are complete for RELRP, NLMP and LMRC. Data from FRtG round 2 will be uploaded and will be completed under a new contract with University of Western Australia.

The screenshot in Fig 4.6 appears when the "Organizations" button is selected. For each organization there is a brief description followed by the number of experiments that organization has on the database. For example the CSIRO Agriculture flagship has 24 individual experiments. Clicking on the institution brings up the list of individual experiments as well as the experiments organized within the projects. Either projects or experiments can then be selected for further investigation.

The screenshot (Fig 4.7) appears when the "Projects" button is selected and in this case the user is taken directly to the list of 72 projects across 4 pages.

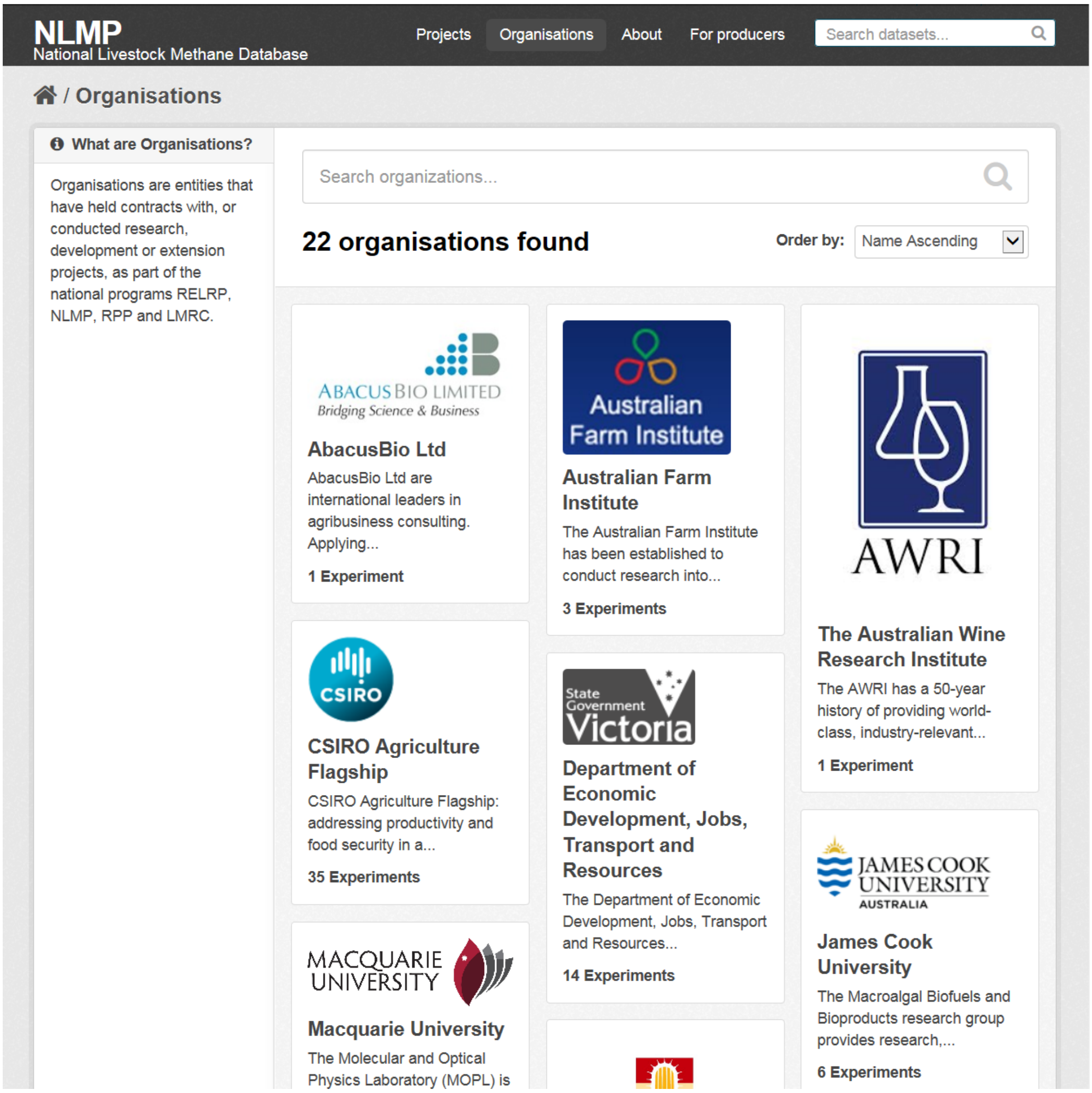


Fig 4.6. CKAN screenshot of the organizations page.

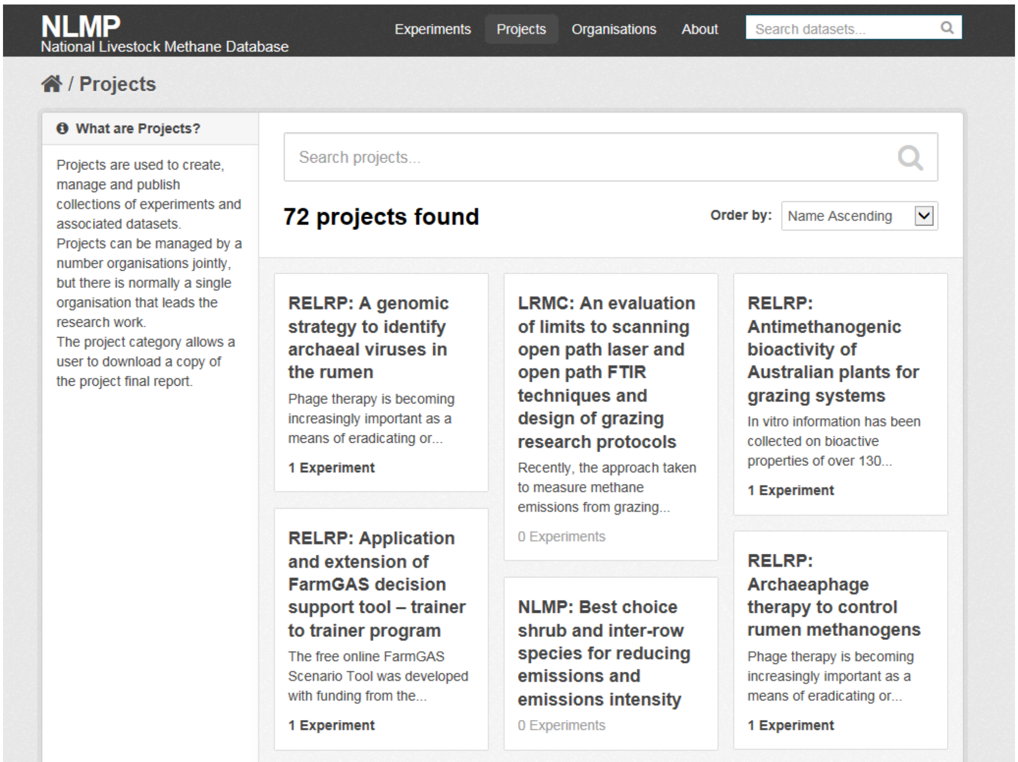


Fig 4.7. CKAN screenshot of the projects page

By way of example if the user moves to the second page of projects and selects organizations selects "Managing carbon in livestock systems: modelling options for net carbon balance" the following screen appears (Fig 4.8).

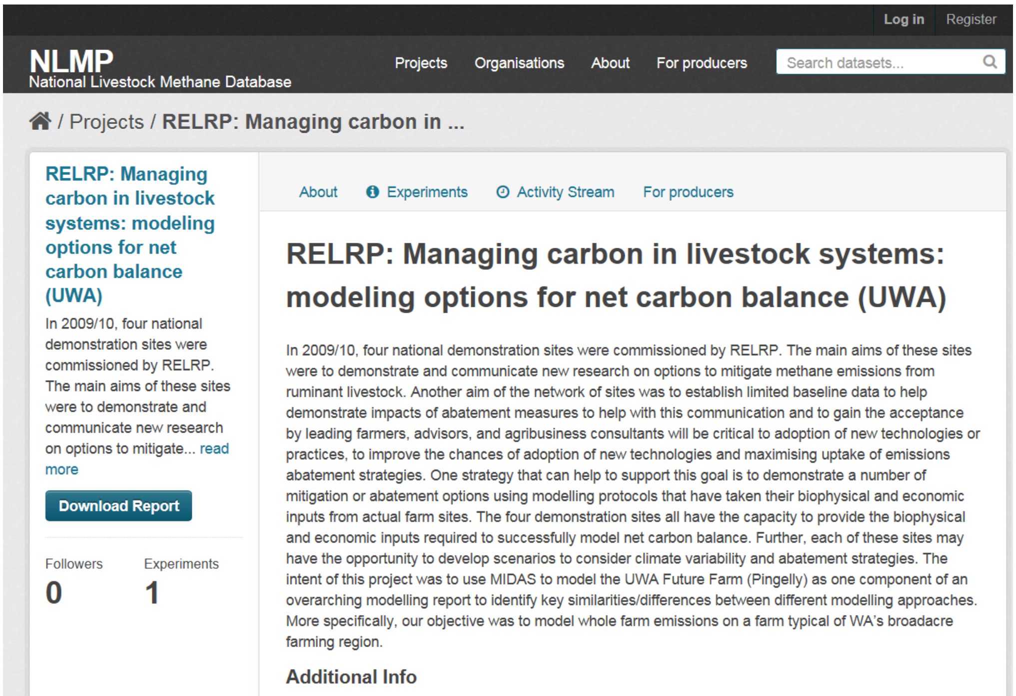


Fig 4.8. CKAN screenshot example of an individual experiment

Clicking in the Experiments tab brings up another screen with tabs to open text, data and CSV files (Fig. 4.9). The user can download the full report, download the data in excel or view and graph the data as a CSV file. There is also a link to any papers that have been published.

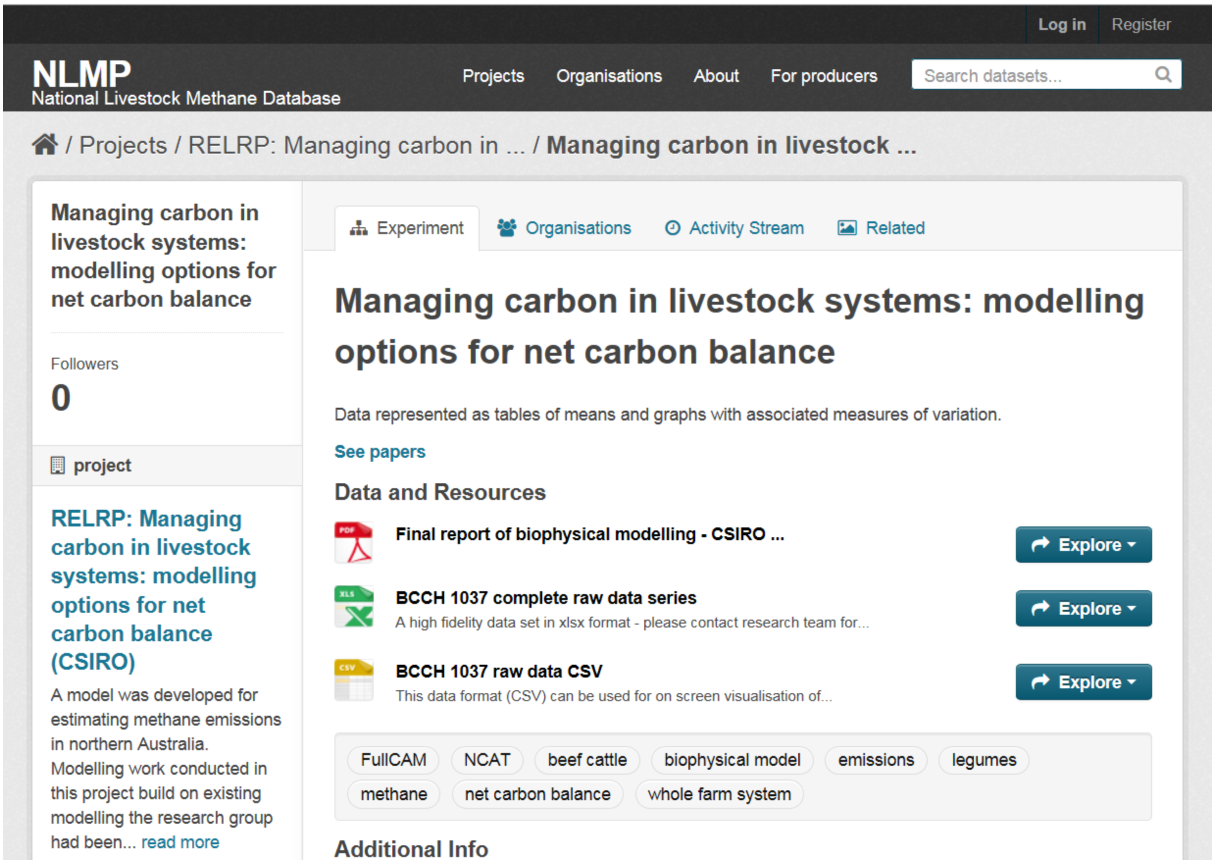


Figure 4.9. CKAN screenshot of an experimental page showing the various data forms to access

4.3.2 The Producer button

The "Producer" button transfers the user to information relating to uploaded projects and experiments that specifically relate to a producer or lay person audience. While the button is now live, only a sample amount of information has been uploaded simply to demonstrate the utility of the button. As for the researcher button there are two levels of CKAN architecture and information can be accessed from both levels.

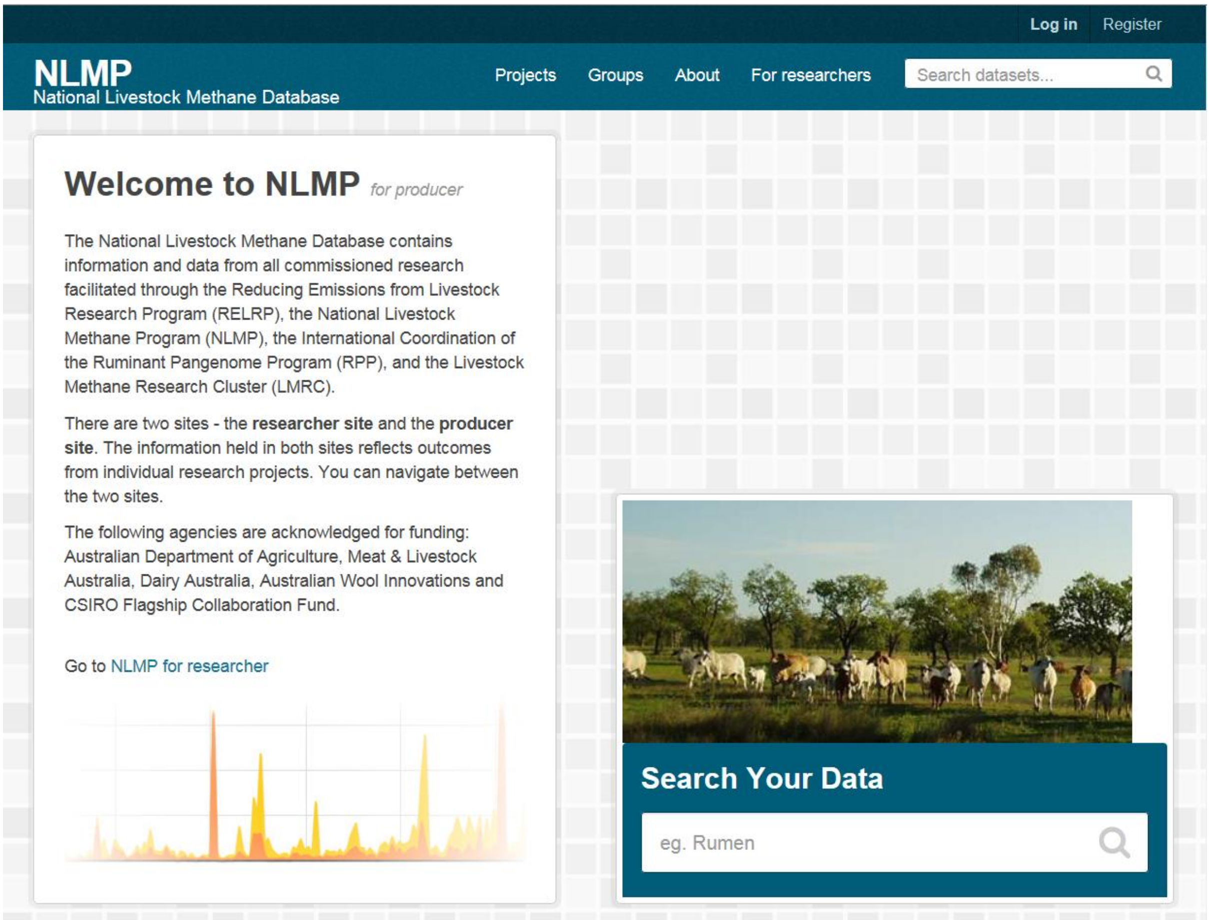


Fig. 4.10 The Producer home page (under construction)

The screenshot in Fig 4.10 appears when the "for producers" button is selected. Currently all data under the researcher button also appears on the producer button. This information will be pared down to only those files that are relevant to producers and addition producer-orientated information will be uploaded under the UWA contract. Navigation is exactly the same as for the researcher button and it is a simple click to switch between the two producer buttons.

Fig. 4.11 shows an example of the type of data that currently resides under the producer button.

Fig. 4.11. Example of the type of material that resides under the producer button (under construction).

5 Discussion

"*All of society's grand challenges require data to be shared and integrated across cultures, scales and technologies*"

Mark Parsons, General Secretary of the Research Data Alliance

5.1 The process

Recent advances in webservices technologies now allow for routine delivery of data, thus unlocking critical datasets for broader use. Indeed, the development of these technologies is transforming the way in which data is stored, shared and used. Animal science has adopted novel methods of handling large data in some fields, such as genetics and genomics, but in general, data storage, management and retrieval in the animal sciences is in its infancy. This project has confirmed that more ordered data oversight in the animal sciences can be facilitated through the use of databases to improve management and data availability.

At the outset of the project the prevailing view was that the database would provide a service for researchers, and principally those researchers actually involved in the projects that were included in the database. However as the project evolved it became clear that the database could serve a much wider audience. This changed the direction of the database development from one principally around storage of datasets to one around storage of a much wider array of information, including reports, papers, data, links to related sites, popular press articles and other related media (See below). The intended audience now includes policy makers, producers, the carbon industry, researchers and the general public – in fact anybody with an interest in methane emission from livestock in Australia and around the World.

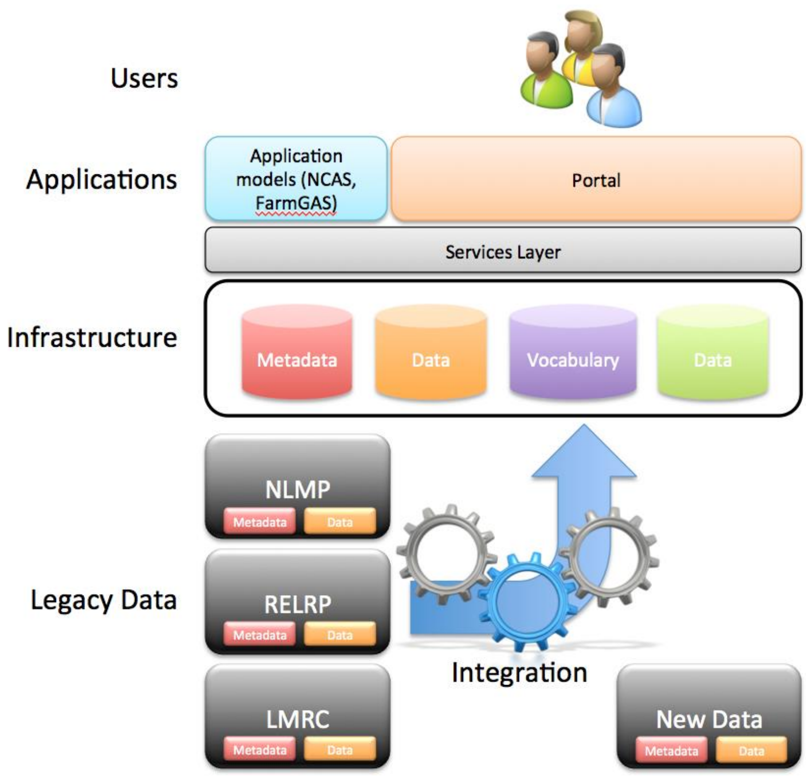


Fig 5.1. Schematic view of database architecture.

Database development followed what is known in the sector as agile iterative methodology. In essence this involved building a simple database to deliver the basics (Fig 5.1) and then building on this in a manner that was adaptive to the needs of the information that was being supplied (Fig 5.2). Critical in this phase was the use of existing information derived from the RELRP program. Following two iterations it became clear that a proprietary database system known as CKAN, which stands for “Comprehensive Knowledge Archive Network”, could be readily adapted to provide the necessary vehicle for information collection, management and accessibility. CKAN is a powerful data management system that makes data accessible – by providing tools to streamline publishing, sharing, finding and using data. CKAN is aimed at organizations wanting to make their data open and available - See more at: http://ckan.org/#sthash.R3972Aco.dpuf. CKAN also offered the advantage of being used by other databases around the world, thus allowing for the possible federation of databases. In other words, it would be possible to collect and integrate data from multiple databases.

Concomitant with the development of the database was the need to establish semantic integration (i.e. definitions of terms or vocabularies) to facilitate information integration. Thus a major component of the work was the building of a glossary with specific definitions for terms, together with a library of searchable terms that facilitate fast and effective searching of the database. Critical in this phase was the creation of a catalogue and the framework within which metadata was stored using a hierarchical data structure. This catalogue had to be conformant to a common profile or schema prior to integration. This structure is outlined in the figure and does add a layer of complexity for individuals not conversant with uploading on a regular basis. However once the concept is grasped it can readily be understood. Nevertheless this was one of the reasons that convinced the research team that a single responsibility for uploading was essential.

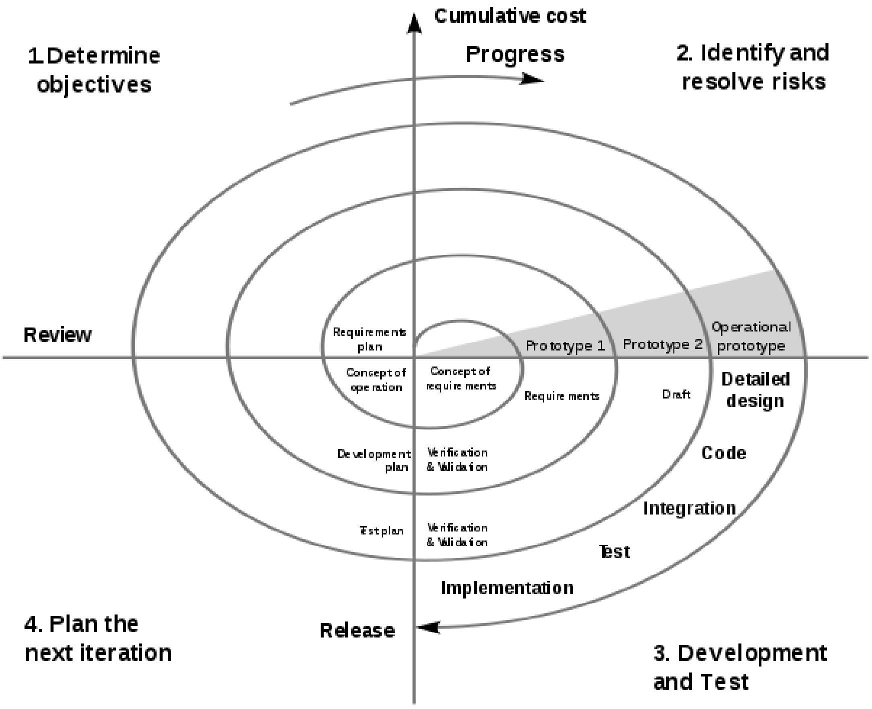


Fig 5.2. Spiral methodology for iterative program development.

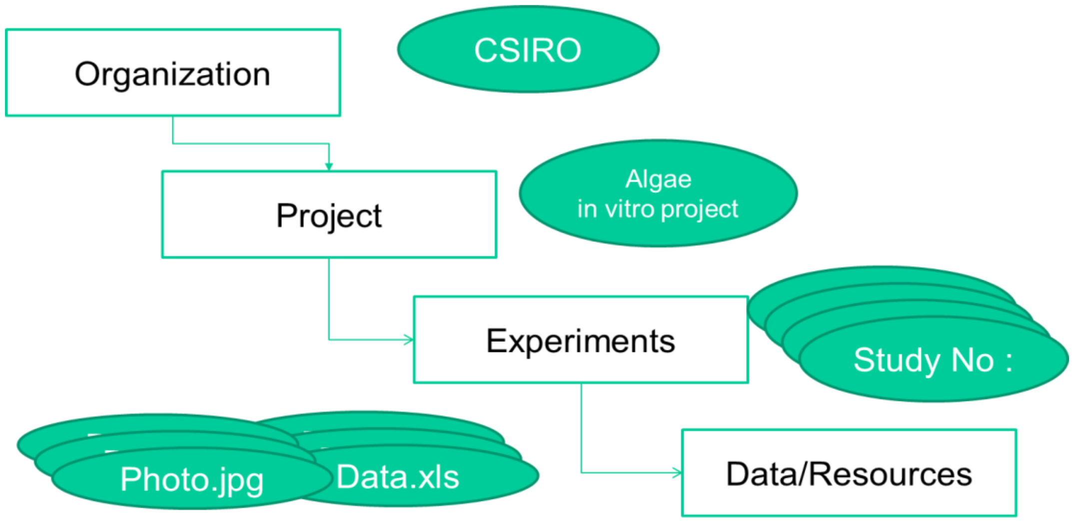


Fig 5.3. Data structure of the database

A major concern of the team was the procurement of secure and long-term storage for the database. However, with the rapid adoption of cloud-based storage systems, this problem was resolved in a manner at massively reduced cost to other alternatives.

5.2 Learnings

The early phase of the project were dogged by several seemingly wicked problems:

- Security and privacy of data
- Where the database is lodged
- How much data should be stored (i.e. to what level of detail –raw data, intermediate data, final data, etc)
- Timely uploading from individual projects

These problems have now been successfully overcome, largely as a result of choosing the CKAN database. By using a proprietary database, data security, to a degree, is built in. The concerns around who has access and the privacy of data were largely overcome by allowing individuals responsible for data to control their own level of security. For example, data can be stored but access limited to the provider of that data. Access to information can be embargoed for a period of time, such as until the research paper is published. There will always be issues around embargoing (can parts of documents be embargoed, how are embargoes lifted?), redacting information and version control. However at this point, none of these issues are of significant concern.

While CSIRO were charged with developing the database it was always understood that CSIRO would not be the repository. Similarly, MLA was also considered unsuitable as maintenance of a database of this sort was out of their domain speciality. Cloud-based storage became the obvious solution. It is relatively inexpensive and CKAN can be maintained with a minimal amount of maintenance and supervision provided as a fee for service from a qualified business entity. University of Western Australia have offered to act as the long-term custodian of the database. Contractual details still need to be resolved. This relationship does not in give UWA control of content, security or use of the data. The data is held by an agnostic commercial provider covered by the usual caveats associated with commercial providers of space in the cloud.

The on-going debate about how much granularity of data was required in the database has now finally been resolved. Initially, it was felt that the database should house large amounts of data that would allow users to access the data and potentially reanalyse it either in isolation or as part of a meta-analysis. This raised concerns in some circles that reinterpretation of data to alter conclusions was unethical and the issue of data attribution was also of concern. Related to this was the point that many organizations already store raw data in their own data storage systems and duplication would simply be a waste of time and money. Added to that was the need for a data-rich database to have a level of complexity and storage capacity quite different to what could be delivered within the remit of the current project.

The problem was resolved by addressing the needs of the likely clients that the database should allow for data to be **Discovered, Downloaded and Displayed.** The decision was taken and endorsed that the level of data to be uploaded was at the level needed to conduct the data analysis for statistical requirements for publication. This was based on the rationale that if publications are in the public domain, the data that was used for the publication should also stand up to public scrutiny. It was also agreed that a consistent level of granularity should apply across all projects. In instances where there are IP or proprietary issues then individual datasets can be locked from public access and the originator of the data has ultimate control. However, it should be reiterated that research conducted with public funds should ethically be open for public scrutiny. With the advent of novel data analytics the research community needs to adapt to the concept that their data can be interrogated by others, provided attribution is given. In the notice to users of the database, clear guidelines on the ethical use of data from this database will be given.

A major failing of the metadata catalogue and portal that was developed for RELRP was the failure of project leaders to ensure that data was uploaded in a timely and consistent manner. This challenge faced the current project. However this was resolved by having uploading centralized and conducted within the remit of the project. The advantages of this mode are that researchers only have to email their information to a central depository, data is then standardized and formatted into a format suitable for upload and there is consistency across projects. This approach has proved to be both time efficient and cost effective and has been completed within the budget of the database project.

Fig. 5.4 demonstrates graphically how the database is now functioning. Data rests in projects in many formats, is of variable detail and is highly heterogeneous and comes in many units. Such data is stored on a range of servers administered by the various research entities. There is a high degree of variability in data management across the research entities.

Research project managers are provided with templates to ensure data is in the required presentation manner. For example excel datafiles should use consistent labelling and adopt a standardized use of rows and columns (e.g. Fig 5.5). Each excel file should also contain a meta-data (data that describes data) sheet – typically the first sheet of a excel spreadsheet file. The meta-data sheet describes the data in detail, such that the data presented are readily understood by those unfamiliar with the experiment. For example if a column in the datasheet is headed sex, then the meta-data file will describe this using pre-determined abbreviations of M, F and S for male, female and steer. These abbreviations are explained in detail.. Units of measure are also clearly defined and should comply with preferred measures or be readily converted to preferred measures. Data is then compiled and uploaded to the database.

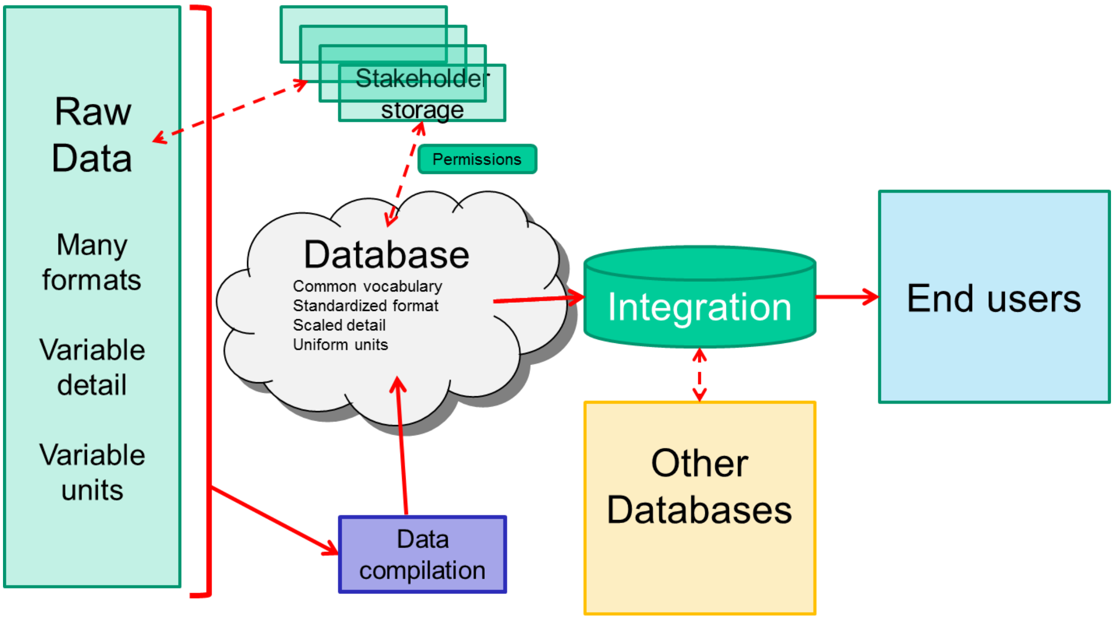


Fig 5.4. The database in action

	A	B	C
1	Acronym	Description	Units
2	Sample ID	Simple numeric unique identifier for each row	None
3	TRT	Treatment designation: N.Beef Rocky is data for collected from Rendel Laboratory, Rockhampton representative of northern cattle fed norhtern diets; N.Beef Townsville is the same as N.Beef Rocky except that data was collected at Lansdown Research Station, Townsville; S.Beef is data for collected from UNE and representative of southern cattle fed southern diets	None
4	Expt	Refers to a partcular experiment within a research centre	None
5	Breed	Refers to the breed of cattle	None
6	SEX	Refers to the sex of the animal: M=male, F=female; S= castrated male (steer)	None
7	DMI	Intake of dry matter per day	kilograms per head per day
8	GEI	Intake of gross energy per day	Megajoules per head per day
9	CH4 (g/d)	Methane emission measured using open-circuit calorimentry	grams methane per head per day
10	CH4 Mj/d	Energy loss as methane measured using open-circuit calorimentry	MJ per head per day
11			
12			
13		Short descripion ot study	
14		These data have been collated from a range of Australain studies evaluating the emission of methane from cattle fed diets containing at least 70% forage.	
15			

Fig. 5.5. Example of a meta-data file

Information can be as data (excel files), word files, PDFs, SCVs, images and links to other databases and websites. There is the option for interactivity between the database and stakeholder storage if that is considered useful and appropriate. The database can be federated with other databases and is available to end users with the various caveats as previously described.

5.3 Observations

This project has been a learning process for all concerned. At the beginning, there was a gulf between the domain specialists in animal science and the technology providers. Database jargon was largely foreign to those expected to embrace the idea and there was a general lack of understanding of the utility of the database. Indeed, the opening statement to one gathering was that “most databases fail”. This is true and the project team were determined to make sure this did not happen in this case. Therefore we insisted the database should above all be simple to use and actually do all the things we wanted it to easily and without fail.

The technologists at first did not understand the needs of the potential users - is this all about big data or an information portal for those interested in Livestock methane? They also underestimated the diversity of data – from gene sequences to the milk production of a cow.

Nevertheless, through frequent interaction between the project team and the data providers, this gulf was narrowed to the point that both sides could understand and communicate readily. Of course, doubters remain, and a lingering fear is that upon completion of the project, ongoing support and use of the database will diminish. A major role now is to secure further funding (achieved) continue to improve useability and relevance of the database. The offer from UWA to have custody of the database should assist in this regard. It is functional and easy to use and “sells itself” when demonstrated, so uptake should be strong with appropriate promotion.

http://ckan.cloudapp.net

6 Conclusions/recommendations

6.1 Conclusions

While the database project has met its objectives the real outcome for this project is that the database becomes established as the key “go to” place for policy makers, the carbon sector, researchers, producers, extension agents and the general public who are looking for information on livestock methane. To achieve this the work cannot cease at the end of the project. In the short term, there is data still being generated in a number of projects within the Rumen Pangenome Project, and projects directly contracted to the Department of Agriculture. Provision has now been made to ensure these projects are uploaded to the database.

From a more strategic perspective the database can be modified in order to potentially serve a wider science base, including for example all GHGs related to animal agriculture. We are currently examining possibilities to facilitate this through demonstration and promotion of the database with interested parties. Related to further development is the issue of custodian. Regardless of adopting a cloud-based platform, it was essential that some form of ongoing oversight was secured. This now appears to have been resolved through additional funding from the Rumen Pangenome Project and support from UWA.

The project has had a strong academic component in relation to how animal science embraces data sharing and the use of open access databases. We believe a publication in Computers in Agriculture or a similar journal would be an appropriate addition to the outputs of the project. Note a paper was presented at the ModNut Conference in Cairns in 2014.

6.2 Recommendations

6.2.1 Future R&D

As previously discussed the Database remains live after the conclusion of the current contract. This ensures that development continues. Based on feedback, the importance of translating the research findings into lay-persons’ language was essential. To accomplish this the Producer Button has been developed. Currently this consists of a mirror image of the researcher database but with changed headings and content. Both researcher and producer sides of the database are interconnected and the user can switch between the two. Currently only a small amount of content has been uploaded to the producer button but uploading or linking to external content will be a major activity under the forthcoming UWA contract.

6.2.2 Practical application of project insights

The impact of this project will be measured by the degree to which it is used by researchers to derive new knowledge from old, by government to inform policy and by producers to make informed decisions on carbon-friendly management decisions. For this to become a reality, the database has to be relevant. Thus it has to be all inclusive. This has been achieved by including all Australian research conducted on livestock methane over the past 7 years. It also has to be easy to navigate and understand. Hence the desire to deliver a producer-orientated version. It has to remain current and functional. Hence the desire to establish a long-term custodian of the database. Notwithstanding these positive steps it will also be essential that the database is popularised. Initially this will require a degree of promotion but eventually we believe the database will sell itself. Success will have been achieved when it appears on the first page of a google search.

6.2.3 Development and adoption activities

The management, access and use of research data is a rapidly evolving field. No longer is it appropriate to simply present the summary of research in the form of a paper where the individual data is hidden behind means and standard errors. No longer is it appropriate to have vague statements about what the data actually represents or how it was measured. Advances in computing power, and particularly with the advent of remote storage systems (i.e. the Cloud) means that metadata and raw or primary processed data can be stored in a manner available to other users. While this presents huge opportunities to mine data, to conduct meta analyses and to re-evaluate findings and conclusions it also presents challenges regarding attribution, professional misconduct and a range of other unforeseen circumstances. While some areas of science have been early adopters of this new technology, many are laggards and the animal sciences in particular fall into the latter category. This project has demonstrated that a collection of research data in the animal sciences can be amassed into an interactive database. The project team have successfully been able to extend the scope of the original mandate. In a related CSIRO project we are exploring the possibility of using the IBM WATSON computing power to develop an artificial intelligence for interrogation of databases. If successful, permission will be sought to use the National Livestock Methane Database as a test case. This, we believe, will be a first in the animal sciences and place this work in the vanguard of how researchers and science will operate into the future.

7 Key messages

7.1 For industry

- The industry awareness of the role of enteric methane emissions on GHGs is increased
- Producers adopt least cost and most effective methane mitigation options
- New and better-informed methodologies are developed for the livestock industries and they are adopted.
- At a value of $6/tonne CO2 equivalent a 20% reduction in emissions from Australian cattle is worth $52 million per year.
- Productivity co-benefits become appreciated by industry increasing uptake and adoption

7.2 For research

- Research findings are used and their impact magnified through exposure to a wider audience and through meta-analysis of existing data
- The rate of scientific discovery is enhanced through better access to data
- Funding for ongoing research is increased through increased awareness of research imact
- Data storage, management and access is enhanced through adoption of new data management technologies.

8 Appendix

8.1 Glossary and meta-data

Term	Meaning of term	Units
Absorption, scattering and emission of radiation	Electromagnetic radiation may interact with other matter (atoms and molecules of a gas for example in the atmosphere) or in the form of particulate, solid or liquid, matter (e.g. aerosols). Matter itself emits radiation reflecting its composition and temperature. Radiation may be absorbed by matter and the absorbed energy may be transferred or re-emitted. Radiation may also be scattered as a result of interaction with matter.	
Adaptation	Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. There are a range of types of adaptation, for example anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal defences, the substitution of normal crop varieties or animal breeds with more temperature resilient crop or animal breeds.	
Aerobic Respiration	This term describes the metabolic processes that generate ATP in association with a chemiosmotic process driven by a respiratory chain that depends on the use of oxygen as the ultimate electron acceptor. Water is the ultimate reduced end product and in animal cells these processes occur in mitochondria where ATP is made by oxidative phosphorylation. In mitochondria, tricarboxylic acid cycle activity and fatty acid oxidation provide most of the reducing equivalents that fuel this process. Amino acids can also serve as oxidisable nutrient substrates in mitochondria after nitrogen removal. Reducing equivalents released by metabolite oxidation reactions in the cytosol can also be shuttled into mitochondria to supply a small proportion of ATP needs.	
Aerosols	A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 μm (a millionth of a metre) that can remain airborne in the atmosphere for several hours, at a minimum. Aerosols may be of either natural or anthropogenic origin (for example from particulates from feedlots). Aerosols may influence local climate in directly through scattering and absorbing radiation, and indirectly, by acting as cloud condensation nuclei or modifying the optical properties. They are of particular interest in the management of the indirect greenhouse gas ammonia in the environment reflecting the	

	adsorption of ammonia on particulates and its re-distribution in the environment.	
Afforestation	Planting of new forests on land that has not historically contained forests (for at least 50 years). For a discussion of the term forest and related terms such as afforestation, reforestation, and deforestation see the IPCC Report on Land Use, Land-Use Change and Forestry (IPCC, 2000). See also the Report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and De-vegetation of Other Vegetation Types (IPCC, 2003).	
Algae	A large group of simple organisms, ranging from single celled phytoplankton to the larger seaweeds. They growth in freshwater and seawater environments. They may have a role as a source of plant secondary compounds that reduce methanogenesis in the rumen as well as acting as an alternative supply of protein to the animal.	
Algorithm	A logical, step-by-step procedure used to solve problems in mathematics and computer programming. In the case of empirical or mechanistic modelling of agricultural systems, an algorithm refers to the conversion of raw data into a biophysical response. The National Greenhouse Gas Inventory uses a range of algorithms to predict the impact of animal or crop production systems on total greenhouse gas emissions.	
Allowable carbon sinks	Under the Kyoto Protocol, allowable carbon sinks include afforestation and reforestation activities undertaken since 1990. Agricultural soils (soil carbon) may also be included. Compliance of allowable carbon sinks is a significant challenge for example measuring changes in soil carbon in agricultural soils is problematic.	
Amino acid, peptide and protein	The basic building block of protein. All amino acids contain an amino (NH_2) end, a carboxyl end (COOH) and a side group (R). In proteins, amino acids are joined together when the NH_2 group of one molecule is cross-linked with the COOH group of the adjacent amino acid.	
Ammonia (NH_3)	A colourless gas with a characteristic pungent smell. Ammonia contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to food and fertilizers. It can be a potent indirect greenhouse gas.	
Ammonia	The loss of nitrogen as ammonia gas from the soil surface following application of urea fertilisers, or when urea is	

volatilisation	deposited from animal wastes. Volatilisation also occurs as a result of a reaction driven by the urease enzyme.	
Ammonium (NH_4^+).	A relatively immobile form of nitrogen in soil and an important nutrient of crops and grassland to which it is supplied as mineral fertilizers, manures and from natural soil processes. It forms the substrate for the nitrification process.	
Antibiotic	A substance produced by bacteria or fungi that destroys or prevents the growth of other bacteria and fungi. Antibiotics are not effective against viruses.	
Anthropogenic emissions	Emissions of greenhouse gases, greenhouse gas precursors (indirect greenhouse gases), and aerosols associated with human activities, including the burning of fossil fuels, deforestation, land-use changes, livestock, fertiliser application etc.	
Antibody	A protein produced by the body's immune system in response to a foreign substance (antigen). An antibody reacts specifically with the antigen that induced its formation and inactivates the antigen.	
Antigen.	Any foreign substance, usually a protein that stimulates the body's immune system to produce antibodies. Antigen reflects its role in stimulating an immune response – antibody generating.	
Annex I, II & B countries (UNFCCC definition)	**<u>Annex I countries</u>** The group of countries included in Annex I (as amended in 1998) to the United Nations Framework Convention on Climate Change (UNFCCC), including all the OECD countries in the year 1990 and countries with economies in transition. Under Articles 4.2 (a) and 4.2 (b) of the Convention, Annex I countries committed themselves specifically to the aim of returning individually or jointly to their 1990 levels of greenhouse gas emissions by the year 2000. By default, the other countries are referred to as Non-Annex I countries. For a list of Annex I countries see http://unfccc.int. **<u>Annex II countries</u>** The group of countries included in Annex II to the United Nations Framework Convention on Climate Change (UNFCCC), including all OECD countries in the 1990. Under Article 4.2 (g) of	

	the Convention, these countries are expected to provide financial resources to assist developing countries to comply with their obligations, such as preparing national reports. Annex II countries are also expected to promote the transfer of environmentally sound technologies to developing countries. For a list of Annex II countries see http://unfccc.int. **Annex B countries** The countries included in Annex B to the Kyoto Protocol that have agreed to a target for their greenhouse-gas emissions, including all the Annex I countries (as amended in 1998) except for Turkey and Belarus. For a list of Annex I countries see http://unfccc.int.	
Anaerobic (rumen processes)	In the absence of oxygen. A process relying on microbial communities that can live without oxygen. Microorganisms that do not take up molecular oxygen from the growth environment are described as living anaerobically. Some species of microorganisms that grow under anaerobic conditions where the oxygen tension of the growth environment is extremely low are known as obligate anaerobes. These organisms are generally killed by the intermediate reactive oxygen species generated when oxygen is partially reduced. ATP production in anaerobic organisms is achieved either by fermentation or anaerobic respiration. Anaerobic conditions are conducive to the conversion of organic carbon into methane (CH_4) rather than carbon dioxide (CO_2) facilitated by methanogenic archaea.	
Anaerobic respiration	The metabolic processes in anaerobic life forms that generate ATP by a process that depends on a chemiosmotic mechanism where the ultimate electron acceptor is not oxygen. The reduced product of the electron transport chain is therefore not water. Methanogens in the reticulo-rumen use part of the carbon dioxide that they take up from the growth environment for this purpose; the product of its reduction is methane. Other organisms can use fumarate reductase for ATP production by anaerobic respiration. Fumarate is reduced by NADH to succinate in a redox cycle which achieves charge separation across a membrane and ATP synthesis is driven by dissipation of the chemical potential energy inherent in the electrochemical ion gradient.	
Anaerobic Digestion	Industrial or farm scale plants of a range of possible sizes used to convert livestock manures and other organic materials into	

(AD) systems	methane and combustible gases for use as a fuel source, with compost as a by-product.	
Anthropogenic GHG	Caused or induced by humans; of human origin. Since about 1750 human activity has increased the concentration of carbon dioxide and other greenhouse gases. Currently, the measured atmospheric concentrations of carbon dioxide are about 100 ppm higher than pre-industrial levels. Natural sources of carbon dioxide emit more than 20 times more CO_2 than anthropogenic sources. However over a 20-year period, emission sources and sinks of CO_2 from natural sources are balanced. As a result of this balance, the atmospheric mole fraction of carbon dioxide remained between 260 and 280 parts per million for the 10,000 years between the end of the last glacial maximum and the start of the industrial era. It is likely that anthropogenic induced warming will have a discernible influence on many physical and biological systems and future warming scenarios suggest sea level rise, increased frequency and severity of extreme weather events, loss of biodiversity and regional changes in agricultural productivity.	
Archaea	The Archaea (singular archaeon) constitute a domain or kingdom of single-celled microorganisms. They are important in the production of methane from labile carbon sources in many ecosystems including the soil and rumen.	
Atmospheric lifetime	The major greenhouse gases are well-mixed in the atmosphere and take many years to leave the atmosphere. Although it is not easy to know with any precision how long it takes greenhouse gases to leave the atmosphere, there are estimates for the principal greenhouse gases. Jacob (1999) defined the lifetime τ of an atmospheric species X in a single box model as the average time that a molecule of X remains in the box. Mathematically τ can be defined as the ratio of the mass m (in kg) of X in the box to its removal rate, which is the sum of the flow of X out of the box, chemical loss of X (L), and deposition of X (D) (all in kg/s). The atmospheric lifetime of a greenhouse gas measures the time required to restore equilibrium following a sudden increase or decrease in its concentration in the atmosphere. Individual atoms or molecules may be lost or deposited to sinks such as the soil, the oceans and other waters, or vegetation and other biological systems, reducing the excess to background concentrations. Carbon dioxide has a variable atmospheric lifetime, and cannot be specified precisely. The atmospheric lifetime of CO_2 is estimated of the order of 30–95 years. This variability reflects removal of CO_2 from the	

	atmosphere by mixing into the ocean, photosynthesis, and other processes. However, it excludes the balancing fluxes of CO_2 into the atmosphere from the geological reservoirs, which have slower characteristic rates. Even though more than half of the CO_2 emitted is removed from the atmosphere within a century, about 20% of emitted CO2 remains in the atmosphere for many thousands of years.	
Attributable process	Attributable processes are any service, material and energy flows that become the product, make the product, and carry the product through its life cycle.	
Autotrophy	Life forms that use carbon dioxide as the sole or principal carbon source for growth are described as autotrophs, and the use of carbon dioxide is called autotrophic carbon dioxide fixation. In the reticulo-rumen the autotrophs are the methanogens and the homoacetogens. Both of these groups of microorganisms use the acetyl CoA pathway of CO_2 fixation. These, and other autotrophs that live in the dark, (and who therefore do not carry out photosynthesis) may also be called chemoautotrophs just to make that point (organisms that carry out photosynthesis are phototrophs and are also autotrophic, hence the descriptor photoautotrophic). The term chemolithoautotrophy can also be applied to the methanogens and the homoacetogens. The "litho" component of the name (from the greek word for stone=inorganic) conveys the idea that these organisms derive reducing equivalents (for reductive biosynthesis and for ATP generation) from the oxidation of hydrogen which is an inorganic compound.	
Avoided emissions	Avoided emissions are reductions in emissions caused indirectly by a product. This is where a product provides the same or similar function as existing products in the marketplace, but with significantly less GHG emissions.	
Bacterium (plural bacteria).	A single-celled, microscopic organism without a distinct nucleus.	
Barrier	Any obstacle to reaching a goal, adaptation or mitigation potential that may be overcome or attenuated by a policy, programme, or measure. Examples of removals of barriers include correcting market failures or reducing the transactions costs in the public and private sectors by, for example, through improving institutional capacity, reducing risk and uncertainty, facilitating market transactions, and enforcing regulatory policies.	

Baseline	The reference from which measurable abatement of greenhouse gases can be determined. This level of greenhouse gas emissions generally reflects business as usual for an agricultural production system or farm.	
Biomass	Plant or animal matter (including agricultural waste) used as a fuel or energy source. Alternatively, the total mass of living matter within a given environmental area.	
Biotechnology	Technology that relies on biological organisms or processes to produce useful products. These include fermentation or vaccines.	
Carbon credits.	A means of reducing the impact of greenhouse gas emissions by establishing a trading scheme that places a value of carbon emitted. Individuals and companies can purchase carbon credits to counteract their emissions. The money is invested in projects that reduce greenhouse gas emissions such as renewable energy, tree planting or energy efficiency projects.	
Carbon Emission Reduction Scheme	A method such as a carbon tax or carbon trading scheme that reduces emissions of carbon (and other greenhouse gases). A carbon tax is a tax imposed on the production or use of fossil fuels based on the carbon content of those fossil fuels. Trading schemes set a limit to the amount of greenhouse gases that can be released. Permits are then allocated to organisations for their carbon emissions and those organisations that reduce emissions below their quota can trade the excess to other organisations.	
Carbon dioxide fertilisation effect	If the concentration of CO_2 is elevated, the growth of plants is stimulated. A doubling of atmospheric carbon dioxide has been shown to increases photosynthesis rate by up to 50 per cent depending on temperature. Experiments show that the effect of increasing concentrations of CO_2 is limited by water or nutrient supply.	
Carbon cycle	The carbon cycle is the flow of carbon (in various forms) through the atmosphere, ocean, landscape and underlying geology. Methanogenesis is the final step in the cycle that is the decay of organic matter and release of methane or carbon dioxide. During organic matter decay, electron acceptors (such as oxygen, ferric iron (Fe^{3+}), sulphate, and nitrate) are depleted, while hydrogen (H_2) and carbon dioxide accumulate along with a range of volatile organic compounds. During the advanced stages of organic matter decay, all electron acceptors are	

	depleted with the exception of CO_2. Only methanogenesis and fermentation can occur in the absence of electron acceptors other than carbon. Fermentation only allows the breakdown of larger organic compounds, and produces small organic compounds (for example the production of short chain fatty acids from cellulose during ruminal fermentation). Methanogenesis effectively removes a range of intermediary products of decay: hydrogen, short chain fatty acids and carbon dioxide. Without methanogenesis, high concentrations of fermentation products would accumulate in anaerobic environments.	
Carbon Sequestration	Terrestrial, or biologic, carbon sequestration is the process by which trees and plants assimilate carbon dioxide and store the carbon. Geologic sequestration is one step in the process of carbon capture and sequestration (CCS), and involves injecting carbon dioxide deep underground where it stays permanently.	
Carbon Capture and Sequestration	Carbon capture and sequestration (CCS) is a set of technologies that can reduce CO_2 emissions from coal- and gas-fired power plants, industrial processes, and other stationary sources of carbon dioxide. It is a three-step process that includes capture of CO_2 from power plants or industrial sources; transport of the captured and compressed CO_2; and underground injection and geologic sequestration, or permanent storage, of that CO_2 in rock formations that are porous and can trap and retain CO_2.	
Carbon Dioxide (CO_2)	A naturally occurring gas. It is the by-product of respiration of microorganisms, plants and animals, burning fossil fuels, burning biomass, land use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and has a global warming potential (GWP) of 1 as defined in the National Greenhouse Energy Reporting Scheme (NGERS) Regulations. It is the third most abundant gas in the atmosphere, essential for plant life and is released by respiration by living organisms.	
Carbon footprint	The total amount of GHG emissions associated with a product along its supply-chain including emissions from consumption, end-of-life recovery and disposal. Usually expressed in kg or t of carbon dioxide equivalent (CO2-eq). It should not be confused with ecological footprint	
Carbon neutral	This is a proposition where a company's carbon emission are effectively reduced to zero through a combination of reducing	

	energy consumption, using renewable energy and offsetting the remainder by, for example, planting trees to sequester CO_2.	
Carbon offsetting	Carbon offsetting is where an investment is made in a project that will lead to the prevention or removal of carbon dioxide from the atmosphere (for example, planting trees or building renewable energy power stations to avoid the construction of coal ones).	
Carbon price	A price on greenhouse gas emissions aims to create a disincentive for their release (and an incentive to capture or avoid them). A carbon price can be imposed through a carbon tax, an emissions trading scheme (which fixes the emission level and allows price to vary) or a variety of other mechanisms	
Carbon trading	The trading of greenhouse gas emission rights. Participants in carbon trading buy and sell certificates that represent specified amounts of emissions or credits for reductions in emissions. By placing a price on carbon emissions there is an incentive to reduce or abate emissions through a range of technologies.	
Cellulolytic (fibrolytic)	Many microorganisms produce cellulases which hydrolyse the glucose polymer cellulose, releasing glucose, obtaining thereby a substrate for chemoheterotrophic growth. Some species secrete these enzymes into the extracellular medium and glucose released from the polymer can also be used as a growth substrate by species that do not make cellulases. The cellulase producers are therefore of primary importance in the metabolic economy of the reticulo-rumen because they provide the growth substrate for other species that would not otherwise grow here.	
Chlorofluorocarbons (CFCs).	These compounds were commonly used as refrigerants in refrigerators and air conditioners, blowing agents in foam plastics and cleaners for computer circuit boards. CFCs do not occur naturally and their increase in the atmosphere is entirely the result of human activity. CFCs are ozone depleting compounds and are restricted or banned from use under the 1987 Montreal Protocol.	
Clean Development Mechanism (CDM)	Defined in Article 12 of the Kyoto Protocol, a CDM is intended to meet two objectives: (1) to assist parties not included in Annex I in achieving	

	sustainable development and in contributing to the ultimate objective of the convention; and (2) to assist parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments. Certified Emission Reduction Units from CDM projects undertaken in non-Annex I countries that limit or reduce greenhouse gas emissions, when certified by operational entities designated by Conference of the Parties/Meeting of the Parties, can be accrued to the investor (government or industry) from parties in Annex B. A share of the proceeds from the certified project activities is used to cover administrative expenses as well as to assist developing country parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.	
Climate	Climate in a narrow sense is defined in terms of the mean and variability of relevant measures (e.g. temperature, rainfall) over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years (World Meteorological Organization definition). Climate in a wider sense is the state, of the climate system and different averaging periods can be used.	
Climate change	Climate change is a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period (e.g. 10 year or longer). Climate change may be due to natural internal or external processes or to anthropogenic changes in the composition of the atmosphere or in land use. The United Nations Framework Convention on Climate Change (UNFCCC) Article 1 defines climate change as: ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’. This definition makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.	
Climate Feedback	A process that acts to amplify or reduce direct warming or cooling effects. Positive feedback reinforces or increases direct warming whilst negative feedback acts to keep a process within	

	certain limits. Positive feedback can work in systems by amplifying a very small effect, changing the previous equilibrium.	
Climate Model	A quantitative way of representing the interactions of the atmosphere, oceans, land surface, and ice. Models can range from relatively simple to highly complex.	
Climate prediction & projection	Climate prediction A climate prediction or forecast is the result of an attempt to produce an estimate of the actual evolution of the climate in the future, for example, at seasonal, inter-annual or long-term time scales. A prediction is highly sensitive to initial conditions and is probabilistic in nature. Climate projection A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or changes in radiative forcing scenarios which are often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasise that climate projections depend upon the emission/concentration/radiative forcing scenario based on assumptions concerning future socioeconomic and technological developments that may or may not be realised. Projections are therefore subject to substantial uncertainty.	
Climate scenario	A plausible but often simplified representation of the future climate, based on a consistent set of climatological relationships that has been constructed for use in investigating the potential consequences of anthropogenic climate change. Climate projections often provide the input data for constructing climate scenarios. Climate scenarios usually require additional information about the current climate. A climate change scenario is the difference between a climate scenario and the current climate.	
Climate sensitivity	The Intergovernmental Panel on Climate Change (IPCC) reports that the equilibrium climate sensitivity refers to the equilibrium change in global mean surface temperature following a doubling of the atmospheric (equivalent) CO_2 concentration or more generally a unit change in radiative forcing (°C/Wm^{-2}). One approach to evaluate the equilibrium climate sensitivity is to use	

	simulations with Coupled General Circulation Models (CGC models). The effective climate sensitivity is a related measure that circumvents the use of CGC models. It is determined from model outputs for evolving non-equilibrium conditions and is a measure of the strengths of the feedbacks at a particular time and may vary with forcing history and climate state.	
Climate System (or Earth System)	The five physical components (atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere) that are responsible for the climate and its variations	
Climate variability	Climate variability is the measures of variation of mean state. For example standard deviations, incidence of extremes or outliers of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).	
CO_2-equivalent	The amount of CO_2 emissions that would cause the same time-integrated irradiative forcing, over a given time horizon, as an emitted amount of a mixture of greenhouse gases. It is obtained by multiplying the emission of a greenhouse gas by its Global Warming Potential (GWP) for the given time horizon. The CO_2 equivalent emission is a standard metric for comparing emissions of different greenhouse gases (IPCC, 4 AR 2007). Carbon equivalents, C(e), are sometimes quoted. To convert from CO_2e to C(e) multiply by 12/44.	
Co-benefit	The benefits of policies that are implemented for various reasons at the same time. For example climate change mitigation policies address greenhouse gas mitigation but also may have an impact on related to objectives of development, sustainability, and equity.	
cohort	Class of animals within a herd defined by their age and sex (e.g. adult females, replacement females, males for fattening).	
Crude protein	The crude protein content of a feed sample represents the total nitrogen (N) in the diet, including true protein and non-protein nitrogen (e.g. urea, ammonia and nitrates depending on the approach taken for analysis).	
Deforestation	Conversion of forest to non-forest land. For a discussion of the term forest and related terms such as afforestation, reforestation, and deforestation see the IPCC Report on Land	

	Use, Land-Use Change and Forestry (IPCC, 2000). See also the Report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and De-vegetation of Other Vegetation Types (IPCC, 2003).	
Denitrification	Microbial processes responsible for the conversion of nitrate to gases including nitrous oxide.	
Diet	Mixed feed ingredients, including water, which is consumed by animals (Ensminger and Olentine, 1980). It includes the amount and composition of feed supplied to an animal for a defined period of time.	
Digestion	Digestion of feeds in the reticulorumen is a complex process. Digestion of feeds results through the fermentation of feed nutrients by microbes in the reticulorumen rather than the animal per se. The main substrates of digestion in the reticulorumen are non-structural carbohydrates (starch, sugar, and pectin), structural carbohydrates (hemicellulose and cellulose), and nitrogen-containing compounds (proteins, peptides, and amino acids). Both non-structural and structural carbohydrates are hydrolysed to monosaccharides or disaccharides by microbial enzymes. The resulting mono- and disaccharides are either assimilated by the microbial biomass or fermented to volatile fatty acids (VFAs) acetate, propionate, butyrate, lactate, valerate and other branched-chain VFAs via glycolysis and other biochemical pathways to yield energy for the microbial cell. Most VFAs are absorbed across the reticulorumen wall, directly into the blood stream, and are used by the ruminant as substrates for energy production and biosynthesis. Protein is hydrolysed to peptides and amino acids by microbial enzymes, which are subsequently transported across the microbial cell wall for assimilation. Peptides, amino acids, ammonia, and other sources of nitrogen originally present in the feed can also be used directly by microbes with little to no hydrolysis. Non-amino acid nitrogen is used for synthesis of microbial amino acids. In situations in which nitrogen for microbial growth is in excess, protein and its derivatives can also be fermented to produce energy, yielding ammonia. Lipids, lignin, minerals, and vitamins play a less prominent role in digestion than carbohydrates and protein. Lipids are partly hydrolysed and hydrogenated, and glycerol, if present in the lipid, is fermented. Some carbon from carbohydrate or protein may be used for de novo synthesis of microbial lipid. High levels of lipid, particularly unsaturated lipid, in the rumen are thought	

	to suppress fermentation activity. Lignin, a polyphenol compound, is recalcitrant to digestion though it can be solubilized by fungi.	
Direct energy	Energy used on-farm for livestock production, for example lighting, heating and cooling.	
Dry Matter	Total weight of feed minus the weight of water in the feed, expressed as a %.	
Dry Matter Digestibility	Dry Matter Digestibility (DMD) is the portion of the dry matter in a feed that is digested by animals at a specified level of feed intake.	
Dry Matter Intake	Dry Matter Intake (DMI) refers to feed intake excluding its water content.	
Ecological footprint	The amount of biologically productive land and water that is needed to supply resources and absorb wastes. Ecological footprints are usually expressed in units of global hectares and the terms should not be confused with carbon footprint.	
Embodied emissions	The term "embodied emissions" combines the emissions from raw material acquisition and pre-processing, production, distribution and transport, installation and end-of-life treatment (i.e. all life cycle stages other than the use stage).	
Emission	Releases to air and discharges to water and land that result in greenhouse gases entering the atmosphere.	
Enhanced Greenhouse Effect	The concept that the natural greenhouse effect has been enhanced by increased atmospheric concentrations of greenhouse gases (such as carbon dioxide, methane, chlorofluorocarbons and nitrous oxide) emitted as a result of human activities. Also known as the anthropogenic greenhouse effect or climate change.	
Embedded energy	Energy or emissions arising during the manufacture of farm inputs, such as fertiliser or feeds.	
Emission factor	Factor that defines that rate at which a greenhouse gas is emitted, e.g. kg CH_4 per animal per year or kg N_2O-N/kg manure N.	
Emissions intensity	Mass of emissions per unit of product, e.g. kg CO_2/kg of meat/milk.	
Emission scenario	A plausible representation of the future development of	

	emissions of substances that confer radiative active (greenhouse gases, aerosols), based on a consistent set of assumptions about driving forces (demographic and socioeconomic development, technological change). Concentration scenarios, derived from emission scenarios, are used as input to climate models to develop climate projections.	
Emission trajectory	A projected time-course of the emission of a greenhouse gas or group of greenhouse gases, aerosols and greenhouse gas precursors.	
Emissions trading	A means of controlling greenhouse gas emissions from organisations and companies. Normally national governments place limits on the total amount of carbon or greenhouse gases that can be released. The Government then provides a number of carbon 'permits' equal to the set limit and companies can compete to purchase permits. In many cases it is cheaper to develop cleaner production technologies (or reduce emissions) to be developed than to buy the permits.	
Enteric Fermentation	Livestock, especially cattle, produce methane as part of their digestion. This process is called enteric fermentation, and it represents one third of the emissions from the agriculture sector	
Enteric Methane	Methane (CH_4) released by ruminants as part of the normal digestive process.	
Feed conversion ratio	Measure of the efficiency with which an animal converts feed into tissue, usually expressed in terms of kg of feed per kg of output (e.g. carcass, milk or protein).	
Feed efficiency	In this an important issue in regard to food conversion efficiency relates to the production of propionate in the reticulo-rumen, the factors that affect it, and the utilization of propionate in the liver of the host ruminant. The presence of methanogens causes increased activities of hydrogen sensitive hydrogenases and thus the pattern of fermentation of some organisms with which they live in syntrophic relationships. For example succinate production is reduced by Ruminococcus flavifaciens when it grows in co-culture with methanogens. Succinate is a substrate for ATP production in some other microorganisms which produce propionate as the end product of their metabolism. Propionate is an important gluconeogenic substrate in the liver of the host ruminant. This means that a reduction in propionate production places increased demands on the use of amino acids for gluconeogenesis in the host liver	

	and kidney cortex. Furthermore, this reduces the availability of amino acids for protein production in host tissues such as muscle. Therefore abundant growth of methanogens in the reticulo-rumen causes reduced food conversion efficiency in the host. The effect can be clearly demonstrated in controlled feeding trials and is one of the reasons for interest in methanogenesis. Another reason depends on the fact that methane is a reduced form of carbon and unlike carbon dioxide cannot be incorporated into bacterial biomass by any of the microbial species found in the reticulo-rumen. Its loss by eructation represents an irretrievable loss of feed carbon and reducing equivalents from the reticulo-rumen.	
Feeding Regime	The whole system of diets fed to animals over the baseline/project period.	
Feeding System	Feeding systems may include forages, food industry by-products, grains, feed blocks, liquids or loose mixes.	
Fermentation	Fermentation is a metabolic process that converts sugar to acids, gases and/or alcohol. It is a normal metabolic process in yeast and bacteria. Fermentation takes place in the absence of oxygen and is used by the cell not to generate energy directly, but to recycle NADH into NAD^+ so that glycolysis can continue, as long as glucose is present. The energy generated by the glycolysis-fermentation (substrate phosphorylation) pathway is comparatively small compared to oxidative phosphorylation. Fermentation consumes NADH, which in aerobic conditions might have been used to generate energy in the electron transport chain.	
Global warming	An increase in the average temperature of the Earth's surface. Global warming is one of the consequences of the enhanced greenhouse effect and may cause worldwide changes to climate patterns.	
Global Warming Potential (GWP)	An index, based upon radiative properties of mixed greenhouse gases, measuring the radiative forcing of a unit mass of a given mixed greenhouse gas in the atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing thermal infrared radiation. The Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame (IPCC, 2006).	

Atmospheric lifetime and GWP relative to CO_2 at different time horizon for various greenhouse gases.

Gas name	**Chemical formula**	**Lifetime (years)**	**Global warming potential (GWP) for given time horizon**		
			20-yr	**100-yr**	**500-yr**
Carbon dioxide	CO_2		1	1	1
Methane	CH_4	12	72	25	7.6
Nitrous oxide	N_2O	114	289	298	153
CFC-12	CCl_2F_2	100	11 000	10 900	5 200
HCFC-22	$CHClF_2$	12	5 160	1 810	549
Tetrafluoromethane	CF_4	50 000	5 210	7 390	11 200
Hexafluoroethane	C_2F_6	10 000	8 630	12 200	18 200
Sulphur hexafluoride	SF_6	3 200	16 300	22 800	32 600
Nitrogen trifluoride	NF_3	740	12 300	17 200	20 700

Grassland or pasture based livestock system	Livestock production systems in which more than 10 percent of the dry matter fed to animals is farm-produced and in which annual average stocking rates are less than ten livestock units per hectare of agricultural land (FAO, 1996).	
Greenhouse gas intensity	The volume of greenhouse gases emitted per unit of energy or economic output. It is a relative measure. If the economy is growing, greenhouse intensity per unit of economic output may be falling but greenhouse gas emissions may be increasing in absolute terms.	
Greenhouse effect	Greenhouse gases absorb thermal infra-red radiation re-emitted by the Earth's surface. This trapping of heat within the surface-troposphere system is known as the greenhouse effect. Thermal infra-red radiation in the troposphere is strongly coupled to the temperature of the atmosphere at the altitude at which it is emitted and tropospheric temperature generally decreases with altitude. Therefore infra-red radiation emitted to space originates from an altitude with a mean temperature of –19°C; an altitude that is equilibrium with net incoming solar radiation. The Earth's surface is on average +14°C and a gradient of temperature exists vertically within the atmosphere. An increase in the concentration of greenhouse gases in the atmosphere leads to increased infra-red opacity and therefore thermal infra-red radiation from the troposphere to space occurs at a higher altitude and a lower temperature. This situation leads to increased radiative forcing and enhancement of the greenhouse effect.	

<table>
<tr><td>Greenhouse gas (GHG)</td><td>Greenhouse gases are gaseous constituents of the atmosphere that result from both natural and anthropogenic reasons. They absorb and emit radiation at specific wavelengths within thermal infrared radiation wavelength emitted by the Earth’s surface, the atmosphere itself, and by clouds. This property leads to the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth’s atmosphere. There are also a range of human-made greenhouse gases such as the halocarbons and other chlorine and bromine containing substances. Many of these are restricted or banned under the Montreal Protocol.
<table>
<tr><th>Gas</th><th>Pre-1750 tropospheric concentration</th><th>Recent tropospheric concentration</th><th>Absolute increase since 1750</th><th>Percentage increase since 1750</th><th>Increased radiative forcing (W/m^2)</th></tr>
<tr><td>Carbon dioxide (CO_2)</td><td>280 ppm</td><td>392.6 ppm</td><td>112.6 ppm</td><td>40.2%</td><td>1.85</td></tr>
<tr><td>Methane (CH_4)</td><td>700 ppb</td><td>1758 to 1874 ppb</td><td>1058 to 1174 ppb</td><td>151.1 to 167.7%</td><td>0.51</td></tr>
<tr><td>Nitrous oxide (N_2O)</td><td>270 ppb</td><td>323 to 324 ppb</td><td>53 to 54 ppb</td><td>19.6% to 20.0%</td><td>0.18</td></tr>
<tr><td>Tropospheric ozone (O_3)</td><td>25 ppb</td><td>34 ppb</td><td>9 ppb</td><td>36%</td><td>0.35</td></tr>
</table></td><td></td></tr>
<tr><td>Halocarbons</td><td>A collective term for the group of partially halogenated organic compounds including the chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), halons, methyl chloride, methyl bromide. These compounds are implicated in the depletion of the ozone layer.</td><td></td></tr>
<tr><td>Herd</td><td>A herd is a group of cattle managed as a unit separate and discrete in terms of physical contact from other groups of cattle. For a particular property all cattle grazed together at the same time on the same area are considered to belong to the same herd.</td><td></td></tr>
<tr><td>Heterotrophy</td><td>Heterotrophic organisms are contrasted with autotrophic life forms in that their carbon needs derive from organic nutrients which they take up from the growth environment. These organic nutrients are also used as the source of reducing equivalents for reductive biosyntheses and, in addition, their oxidation provides the free energy needed to support a chemiosmotic mechanism which powers ATP synthesis. Animals are heterotrophs, and most microorganisms are heterotrophs. Green plants are photoautotrophs. Methanogens are</td><td></td></tr>
</table>

	chemoautotrophs.	
Homoacetogen	Acetate is the predominant end product of the chemoheterotrophic lifestyles of the mixed population of microorganisms that live in the reticulo-rumen. Many species produce acetate but one group; the homoacetogens are particularly important because they can live both as chemoautotrophs (like methanogens) generating ATP in association with a chemiosmotic mechanism, and as chemoheterotrophs deriving ATP also by phosphoryl group transfer in a fermentation pathway. They have only recently been identified in the reticulo-rumen and since they produce mainly acetate as the end product of their metabolism they are undoubtedly partly responsible for the predominance of acetate as an end product of microbial metabolism.	
(Climate change) Impacts	The effects of climate change on natural and human systems. Impacts (subject to adaptation) are either potential or residual: Potential impacts: all impacts that may occur given a projected change in climate, without considering adaptation. Residual impacts: the impacts of climate change that would occur after adaptation.	
Indirect radiative effects	Some gases have indirect radiative effects irrespective of their classification as greenhouse gases. The indirect radiative effect can result in two ways. First they may decompose in the atmosphere and produce another greenhouse gas. For example methane and carbon monoxide (CO) are oxidized to yield carbon dioxide. Secondly, chemical reactions in the atmosphere involving these gases change the concentrations of greenhouse gases. For example, the destruction of non-methane volatile organic compounds (NMVOC) in the atmosphere can produce ozone. Methane has a number of indirect effects in increasing radiative forcing. First, the interaction with hydroxyl radical (OH) yields CO_2, however the quantity of OH radical is finite. Therefore as the concentration of OH in the atmosphere decreases, the atmospheric lifetime of methane effectively increases and therefore an increase in overall radiative effects results. Secondly, the oxidation of methane can produce ozone. Third, the destruction of methane also yields water. Finally oxidation of CO and NMVOC produce CO_2 through removals of OH from the atmosphere leading to higher concentrations of methane. Halocarbons have an indirect effect because they destroy	

	stratospheric ozone. Finally hydrogen can lead to ozone production and CH_4 increases as well as producing water in the stratosphere.	
Indirect N_2O emissions	Indirect emissions of nitrous oxide result from two different nitrogen loss pathways. These pathways are (1) the volatilization/emission of nitrogen as NH_3 and NO_x and the subsequent deposition of these forms of nitrogen as ammonium (NH_4^+) and oxidised nitrogen (NO_x) on soil and water, and (2) the leaching and runoff of nitrogen from synthetic and organic nitrogen fertilizer inputs, crop residues, mineralization of nitrogen through land use change or management practices, and urine and dung deposition from grazing animals, into groundwater, riparian areas and wetlands, rivers and eventually the coastal ocean.	
Kyoto Protocol	The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1997 at Kyoto, Japan. Countries included in Annex B of the Protocol (most Organization for Economic Cooperation and Development countries and countries with economies in transition) agreed to reduce their anthropogenic greenhouse gas emissions (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride) by at least 5% below 1990 levels in the commitment period 2008 to 2012.	
Land use and Land-use change	Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type. The term land use is also used in the sense of the social and economic purposes for which land is managed (for example grazing, timber extraction, and conservation). Land-use change refers to a change in the use or management of land which may lead to a change in land cover. Land cover and land-use change may have an impact on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases as well as other properties of the climate system and may thus have a radiative forcing and/or other impacts on climate. See also: the IPCC Report on Land Use, Land-Use Change, and Forestry (IPCC, 2000).	
LCA (Life Cycle	A complete investigation and valuation of the environmental impacts of a given product or service throughout its life. The LCA	

Analysis)	measures what is needed during production and what is produced from 'cradle to grave'. This measurement includes energy and materials used for obtaining the raw materials for the product, product manufacture and assembly, transport of the product, its use and disposal. Wastes produced during the product's life are also accounted for.	
life-cycle emissions	Emissions of greenhouse gases throughout the full life-cycle of a given product or service. Emissions are not only from the generation of electricity, but also from the production of the energy and materials needed to build, maintain and operate the plant, as well as from disposal of wastes and decommissioning.	
Manure N	Nitrogen in manure.	
ME (metabolizable energy).	The portion of the energy present in a feed that can be utilized by livestock for all metabolic functions (maintenance, growth, pregnancy, lactation).	
Methane (CH_4)	Methane is one of the six greenhouse gases to be mitigated under the Kyoto Protocol. It is a greenhouse gas produced under anaerobic conditions for instance in the rumen, manure stores, and wetlands including rice paddies and landfill sites. Methane is produced as part of normal digestive processes in many animals including ruminants. During digestion, microbes resident in an animal's digestive system ferment food consumed by the animal. This microbial fermentation process, referred to as enteric fermentation, produces CH_4 as a by-product, which can be exhaled or eructated by the animal. The amount of CH_4 produced and emitted by an individual animal depends primarily upon the animal's digestive system, and the amount and type of feed it consumes. Methane has a high 100-year GWP at 34 times that of CO_2. The concentration of methane in Earth's atmosphere in 1998, expressed as a mole fraction, was 1745 nmol/mol (parts per billion, ppb). By 2008 global methane concentrations had risen to 1800 nmol/mol.	
methanogen	Methanogens are microorganisms that produce methane as a metabolic by-product in anoxic conditions. They are classified as archaea, a domain quite distinct from bacteria. Methanogens are common in wetlands, soils and in the digestive tracts of animals such as ruminants and humans. Methanogens are not to be confused with methanotrophs which consume methane for their carbon and energy requirements	

methanotrophs	Methanotrophic organisms use methane as a carbon source for growth and they use aerobic respiration to make ATP using reducing equivalents released by methane oxidation. Methanotrophs occur in both aerobic and anaerobic conditions. They are mostly found in soils but also occur in a range of environments associated with methane such as landfill, marshes, rice paddies and the ocean.	
Methane Conversion Factor (MCF)	The percentage of the manure's maximum methane producing capacity that is achieved during manure management. It is reported on individual manure management systems by state in the National Greenhouse Gas Inventory and the fraction of waste allocated to each of these systems using state defaults in the Inventory or farm specific data.	
Methanogenesis	Bacterial conversion of methanogenic substrates [acetate (CH_3COO^-), formate ($CHOO^-$), hydrogen (H_2), carbon dioxide (CO_2)] into methane (CH_4) and carbon dioxide (CO_2). Methanogenesis or biomethanation is the formation of methane by methanogens. The production of methane is an important and widespread form of microbial metabolism. In most environments, it is the final step in the decomposition of biomass. The methane produced during methanogenesis cannot be used by the host ruminant, nor by other microorganisms, and it is lost from the reticulo-rumen by eructation. This represents loss of feed carbon and reduction of methanogenesis is a high priority.	
Methane sinks	Global methane concentrations have been relatively stable for a long period reflecting the offset of total methane produced by natural methane removal methods (methane 'sinks'). The most important sink for methane is the troposphere (the lowest level of Earth's atmosphere). In the troposphere, the hydroxyl radical (OH) reacts with methane and other gases and converts the greenhouse gas to CO_2 and water vapour. Tropospheric oxidation can remove >500 Mt of methane per year. Smaller amounts of methane (40 Mt) are removed from stratosphere through the same type of reaction. Methanotrophs in soils can remove up to 30 Mt of methane each year.	
Microbial ecosystem	Microbes in the reticulorumen include bacteria, protozoa, fungi, archaea, and viruses. Bacteria, along with protozoa, are the predominant microbes and by mass account for 40-60% of total microbial matter in the rumen. They are categorized into several functional groups, such as fibrolytic (structural carbohydrates), amylolytic (non-structural carbohydrates), and proteolytic	

	(protein) digesters. Protozoa (40-60% of microbial mass) derive their nutrients through phagocytosis of other microbes, and degrade and digest feed carbohydrates, especially starch and sugars, and protein. Although protozoa are not essential for rumen functioning, their presence has pronounced effects. Ruminal fungi make up only 5-10% of microbes and are in low numbers in animals fed low fibre rations. Despite their low numbers, the fungi still occupy an important niche in the rumen because they hydrolyse some ester linkages between lignin and hemicellulose or cellulose, and help break down digesta particles. Rumen Archaea, approximately 3% of total microbes, are mostly autotrophic methanogens and produce methane through anaerobic respiration. Most of the hydrogen produced by bacteria, protozoa and fungi is used by these methanogens to reduce carbon dioxide to methane. The maintenance of low partial pressure of hydrogen by methanogens is essential for proper functioning of the rumen. Viruses are present in unknown numbers and do not contribute to any fermentation or respiration activity. However, they do lyse microbes, releasing their contents for other microbes to assimilate and ferment in a process called microbial recycling, although recycling through the predatory activities of protozoa is quantitatively more important. Microbes in the reticulorumen eventually flow out into the omasum and the remainder of the digestive tract. Under normal fermentation conditions the environment in the reticulorumen is weakly acidic and is populated by microbes that are adapted to a pH between roughly 5.5 and 6.5. The abomasum is strongly acidic (pH 2 to 4) and lyses reticulorumen flora and fauna as it flows from the omasum to the rest of the digestive tract. Lysed microbial biomass is digested in the small intestine and smaller molecules (mainly amino acids) are absorbed and transported in the portal vein to the liver. The digestion of these microbes in the small intestine is a major source of nutrition to the ruminant, as microbial crude protein usually supplies 60 to 90% of the total amount of amino acids absorbed.	
Mitigation	Technological change and substitution that reduce resource inputs and emissions per unit of output. Although social, economic and technological policies produce emission reductions, mitigation refers to the implementation of policies to reduce greenhouse gas emissions and enhance sinks.	
Mitigation Potential	Mitigation potential is the amount of mitigation that could be realised over time. Market potential is the mitigation potential	

	based on private costs and private discount rates which might be expected to occur, if forecast market conditions and policies and measures are in place. Economic potential is the mitigation potential that takes into account social costs and benefits and social discount rates, assuming that market efficiencies are improved by policies and measures and barriers are removed. Technical potential is the amount of mitigation that is possible by implementing a technology or practice that has already been demonstrated as successful. No explicit reference to costs is made.	
Mixed farming system	Livestock production systems in which more than 10% of the dry matter fed to livestock comes from crop by-products and/or stubble or more than 10% of the value of production comes from non-livestock farming activities (FAO, 1996).	
model	A mathematical description of the problem. To set up a model, a problem is simplified and only those aspects that can be represented mathematically are included. After the problem is solved mathematically, tentative solutions are translated back to the real situation, as possible real solutions. At this stage the inadequacy of the simple model may be revealed, and some parts of the process may need to be changed.	
Montreal Protocol	An intergovernmental protocol signed in 1987 which established restrictions for the manufacture and use of ozone-depleting substances in an international effort to reduce ozone depletion. The Protocol is regularly revised.	
Nitrogen Cycle	The natural cycle of nitrogen through the atmosphere, plants, animals, and microorganisms that live in soil and water. Nitrogen takes on a variety of chemical forms throughout the nitrogen cycle, including nitrate (NO_3) nitrous oxide (N_2O) and nitrogen oxides (NO_x).	
nitrogen fixation	The process of producing nitrogen compounds by combining nitrogen from the air with other substances. This is a microbial process. Most nitrogen-fixing bacteria live in the soil or water. However an important group can generate nodules on the roots of legumes such as lucerne, peas, beans and clovers.	
Nitrogen Oxides (NO_x)	Nitrogen oxides cover the gases nitric oxide (chemical formula NO) and nitrogen dioxide (chemical formula NO_2). The main sources of the gases in urban areas are motor vehicle exhaust, gas heating and cooking, and home heating appliances.	

Nitrate	Nitrate is a polyatomic ion with the molecular formula NO_3^- and a molecular mass of 62.0049 g mol^{-1}. Almost all inorganic nitrate salts are soluble in water at room temperature. Inorganic sources of nitrate which can be used for supplementation of animals are calcium nitrate hexahydrate, ammonium nitrate, ammonium nitrate phosphate. Nitrate is a competitor for hydrogen in the rumen and hence a possible abatement technology.	
Nitrous Oxide	One of the main greenhouse gases to be abated under the Kyoto Protocol. The main anthropogenic source of nitrous oxide is agriculture (soil and animal manure management), but important contributions also come from sewage treatment, combustion of fossil fuel, and chemical industrial processes. The GWP of nitrous oxide is 310 times CO_2.	
Non-Methane Volatile Organic Compounds (NMVOCs)	Organic compounds, other than methane, that are involved in atmospheric photochemical reactions	
Non-ruminant animals	Non-ruminant animals (pigs, horses) produce CH_4 emissions through enteric fermentation, although this microbial fermentation occurs in the large intestine. These non-ruminants emit significantly less CH_4 on a per-animal basis than ruminants reflecting differences in microbial processes and ecosystem structure	
Ozone (O_3)	In the troposphere, ozone is created both naturally and by photochemical reactions. Tropospheric ozone acts as a greenhouse gas (photochemical smog) and plays a dominant role in the stratospheric radiative balance. In the stratosphere, ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen (O_2). Depletion of stratospheric ozone, due to chemical reactions that may be enhanced by climate change, results in an increased ground-level flux of ultraviolet (UV-) B radiation.	
Ozone Depleting Substance (ODS)	A family of man-made compounds that includes, but are not limited to, chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These compounds have been shown to deplete stratospheric ozone.	

Ozone Layer	The layer of ozone that begins approximately 15 km above Earth surface and thins to an almost negligible amount at about 50 km. It shields the Earth from harmful ultraviolet radiation from the sun. The highest natural concentration of ozone (approximately 10 parts per million by volume) occurs in the stratosphere at approximately 25 km above Earth. The stratospheric ozone concentration changes throughout the year as stratospheric circulation changes with the seasons. Natural events such as volcanoes and solar flares can produce changes in ozone concentration, but man-made changes are of the greatest concern	
Particulate matter (PM)	Very small pieces of solid or liquid matter such as particles of soot, dust, fumes, mists or aerosols. The physical characteristics of particles, and how they combine with other particles, are part of the feedback mechanisms of the atmosphere.	
pasture	Areas of land vegetated with grasses or other plants suitable for grazing by livestock.	
peptide	A molecule consisting of a short chain of amino acids. Longer chains of amino acids are called proteins.	
protein	A large molecule composed of a linear sequence of amino acids. This linear sequence is a protein's primary structure. Proteins are essential to the structure and function of cells.	
Radiative forcing	Radiative forcing is the change in the net, downward minus upward, irradiance (W/m^2) at the tropopause resulting from a change in an external driver (e.g. change in the concentration of carbon dioxide). Radiative forcing is computed with all tropospheric properties held fixed at their unperturbed values, and after allowing for stratospheric temperatures, if perturbed, re-adjusting to radiative-dynamical equilibrium. Radiative forcing is further defined as the change relative to the year 1750 and refers to a global and annual average value.	
Parts per (concentration)	Parts Per Billion (ppb) Number of parts of a chemical found in one billion parts of a particular gas, liquid, or solid mixture. Parts Per Million by Volume (ppmv) Number of parts of a chemical found in one million parts of a particular gas, liquid, or solid.	

	Parts Per Trillion (ppt) Number of parts of a chemical found in one trillion parts of a particular gas, liquid or solid.	
ration	The combination of feed materials constituting the animal's diet.	
Redox-balance	In anaerobic chemoheterotrophic organisms where ATP production occurs in fermentation pathways by phosphoryl group transfer, production of the necessary high phosphoryl group transfer metabolites involves intermediary oxidation reactions where NAD or NADP are used as the oxidizing agents. Since oxygen is not available as the ultimate electron acceptor for regeneration of the oxidized forms of these intermediary electron carriers a metabolite of the original organic growth substrate has to be used for this purpose. Examples are the reduction of pyruvate to produce lactate or the reduction of acetaldehyde to produce ethanol. Rumen microorganisms utilize a diverse array of these and other such redox couples to achieve redox balance.	
Reforestation	Planting of forests on lands that have previously contained forests but that have been converted to some other use. See Report on Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types (IPCC, 2003)	
Resilience	A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment	
Rumen	The large first compartment of the stomach of a ruminant from which food is regurgitated for rumination and in which cellulose is broken down by the action of symbiotic microorganisms. The rumen, for the larger part of the reticulorumen, which is the first chamber in the alimentary canal of ruminant animals. It serves as the primary site for microbial fermentation of ingested feed.	
Ruminant animals	Ruminant animals (e.g., cattle, buffalo, sheep, goats, and camels) are the major emitters of CH_4 reflecting the rumen in which microbial fermentation breaks down the feed they consume into products that can be absorbed and metabolized. The microbial fermentation that occurs in the rumen enables them to digest plant cell walls that non-ruminant animals	

	cannot utilise	
Seasonal Measurement	Measurement at least once in the second month of each season (i.e. summer, autumn, winter, spring) of pasture based feed sources. Pasture feed sampling must be conducted in the second month to minimise seasonal cross over.	
Sink	Any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere.	
Soil Carbon	A major component of the terrestrial biosphere pool in the carbon cycle. The amount of carbon in the soil is a function of the historical vegetative cover and productivity, which in turn is dependent in part upon climatic variables	
Source	Source mostly refers to any process, activity or mechanism that releases a greenhouse gas, an aerosol, or a precursor of a greenhouse gas or aerosol into the atmosphere.	
sustainable	An activity that is capable of being maintained at a specific level without depleting natural resources or causing excess damage to an ecosystem.	
Stratification and mixing of digesta	The distribution of digesta in the rumen is not uniform, but is stratified into gas, liquid, and particles of different sizes, densities, and other physical characteristics. Digesta does not merely enter and exit the rumen it is subject to extensive mixing with the microbial ecosystem. Feed ingesta, water and saliva enter through the rumen to form a soild and liquid pools. Liquid will ultimately escape from the reticulorumen from absorption through the wall, or through passing through the reticulo-omosal orifice, as digesta does. However, since liquid cannot be trapped in the mat as digesta can, liquid passes through the rumen much more quickly than digesta does. Liquid often acts as a carrier for very small digesta particles, such that the dynamics of small particles is similar to that of liquid. The uppermost area of the rumen, the headspace, is filled with gases (such as methane, carbon dioxide, and, to a much lower degree, molecular hydrogen) released from fermentation and anaerobic respiration of food. These gases are regularly expelled from the reticulorumen through the mouth, in a process called eructation	
Sulphur hexafluoride (SF_6)	One of the six greenhouse gases named for abatement under the Kyoto Protocol. It is largely used in heavy industry to	

	insulate high-voltage equipment and to assist in the manufacturing of cable-cooling systems and semi-conductors. It is however used in rumen studies to act as a proxy for methane production. The global warming potential of SF6 is 22,800.	
Synthetic N	Nitrogen in the form of manufactured fertilisers, such as ammonium nitrate.	
Syntrophy	Syntrophy is the association between two species of microorganisms, growing in the same culture environment, where each exhibits growth characteristics that depend on the presence of the other organism. In the reticulo-rumen there are cases where methanogens grow in syntrophic relations with other species of microorganisms. The methanogens depend on the hydrogen and carbon dioxide produced by other species and some of these other species (such as Ruminococcus) grow better in the presence of the methanogens because of the altered patterns of redox balance associated with the reduced partial pressure of hydrogen in the growth environment (due to interspecies hydrogen transfer	
Tiers	The definition in IPCC (2006) is that a tier corresponds to a progression from the use of simple equations with default data (Tier 1 emission factors), to country-specific data in more complex national systems (Tier 2 & 3 emission factors). Tiers implicitly progress from least to greatest levels of certainty as a function of methodological complexity, regional specificity of model parameters, spatial resolution and the availability of activity data.	
Trace Gas	Any one of the less common gases found in the Earth's atmosphere. Nitrogen, oxygen, and argon make up more than 99 percent of the Earth's atmosphere. Other gases, such as carbon dioxide, water vapour, methane, oxides of nitrogen, ozone, and ammonia, are considered trace gases. Although relatively unimportant in terms of their absolute volume, they have significant effects on the Earth's weather and climate.	
Uncertainty	Uncertainty refers to the range in data for a specific parameter. The term uncertainty assessment refers to a systematic procedure to quantify or qualify the uncertainty in a product inventory.	
United Nations Framework Convention on Climate Change	The Convention was adopted on 9 May 1992 in New York and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries. Its objective is the “stabilisation of greenhouse gas concentrations in the atmosphere at a level that would	

(UNFCCC)	prevent dangerous anthropogenic interference with the climate system". Under the Convention, Parties included in Annex I (all OECD member countries in the year 1990 and countries with economies in transition) aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000. The Convention entered in force in March 1994.	
vaccine	A preparation consisting of antigens of a disease-causing organism which, when introduced into the body, stimulates the production of specific antibodies or altered cells. This produces an immune response to the disease-causing organism. The antigen in the preparation can be whole disease-causing organisms (killed or weakened) or parts of these organisms	
Volatile Fatty Acids	Volatile fatty acids (VFAs) are short chain fatty acids of six carbons or fewer. They are formed as a by-product of fermentation in the digestive tract. They are represented predominantly acetic (C2), propionic (C3) and butyric (C4) acids in the rumen.	

8.2 National Livestock Methane Database user guidelines

This database was created to combine information created under a series of research programs conducted in Australia since 2009. The programs were "Reducing Emissions from Livestock Research Program", "National Livestock Methane Program" and the "Livestock Methane Research Cluster". In its current format the database is primarily of use to researchers but preliminary steps have been taken to include a Producer button, making it equally relevant to producers. Information is stored in a logical and systemic framework which is freely accessible (with some restrictions). Uploaded information, is easily searchable and can be viewed or downloaded for interrogation (p*lease note that the database is still under development).*

1) The Homepage

The database can be accessed at HTTP://ckan.cloudapp.net. Upon login, the user is provided with a "welcome to NLMP" home page. This includes a brief introduction and buttons;

- About
- For Producers/For Researchers
- Organizations
- Projects.

These buttons are used for navigating around the database. The **About** button provides general background information on the database.

The **For Producers/For Researchers** button is used to switch between the two versions of the database (Figure 1).

Organizations take you to a list of the 22 organizations that have contributed to the database and **Projects** takes you to the 72 current projects in the database.

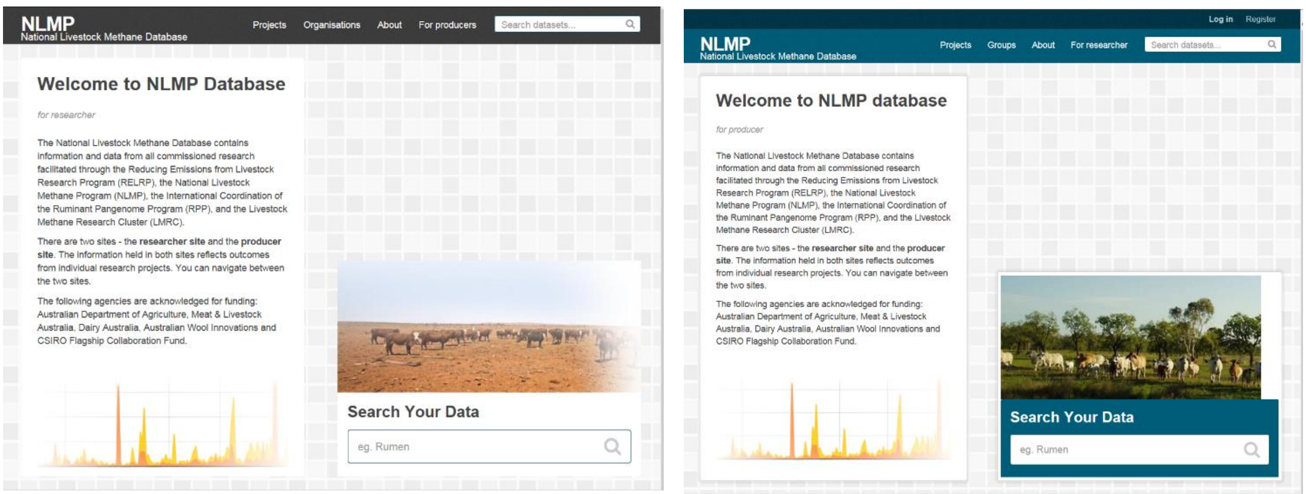


Figure 1. The Database homepages for producers and researchers

2) The Researcher database

Within the **Researcher** database there is a hierarchical structure of **Organizations** and nested within **Organizations** we have **Projects** and within **Projects** we have **Experiments.** Both **Organizations** and **Projects** can be accessed directly from buttons on the home page, while **Experiments** can only be accessed via the **Projects.** Selecting any of these options will bring up a page with information sorted according to the hierarchical level selected (See Figure 2).

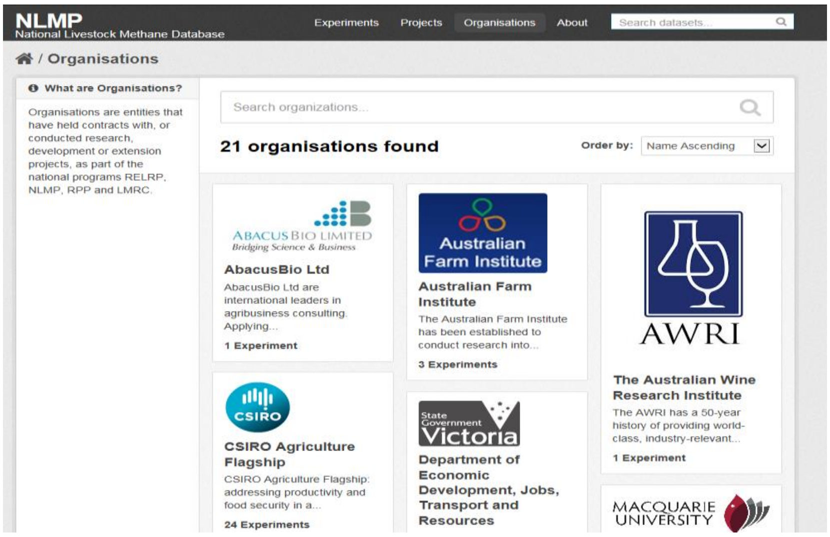


Figure 2a. Screenshot of information arranged by "organization".

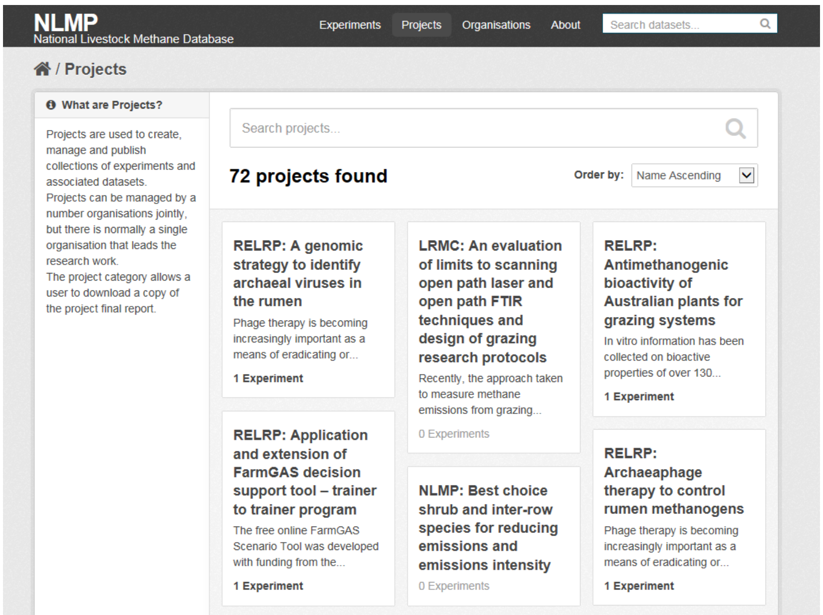


Figure 2b. Screenshot of information arranged by "Project".

3) Navigating from Organizations or Projects

Whenever **Organizations** are listed, clicking on an organization brings up an overview page of all projects associated with that organization (Figure 3) . By moving the cursor over an organization and clicking, the use will bring up a list of all projects in that organization (Figure 4). The process is exactly the same from the **Projects** page, but information is arranged around projects not organizations. On the **Organizations** page, if you select CSIRO, 36 project are found. Moving the cursor over the title of the first project (Managing carbon in livestock systems: modelling options for net carbon balance) and clicking brings up a screen with several features (Figure 5). There is a link to the PDF of the final report, the data and a raw data CSV file.

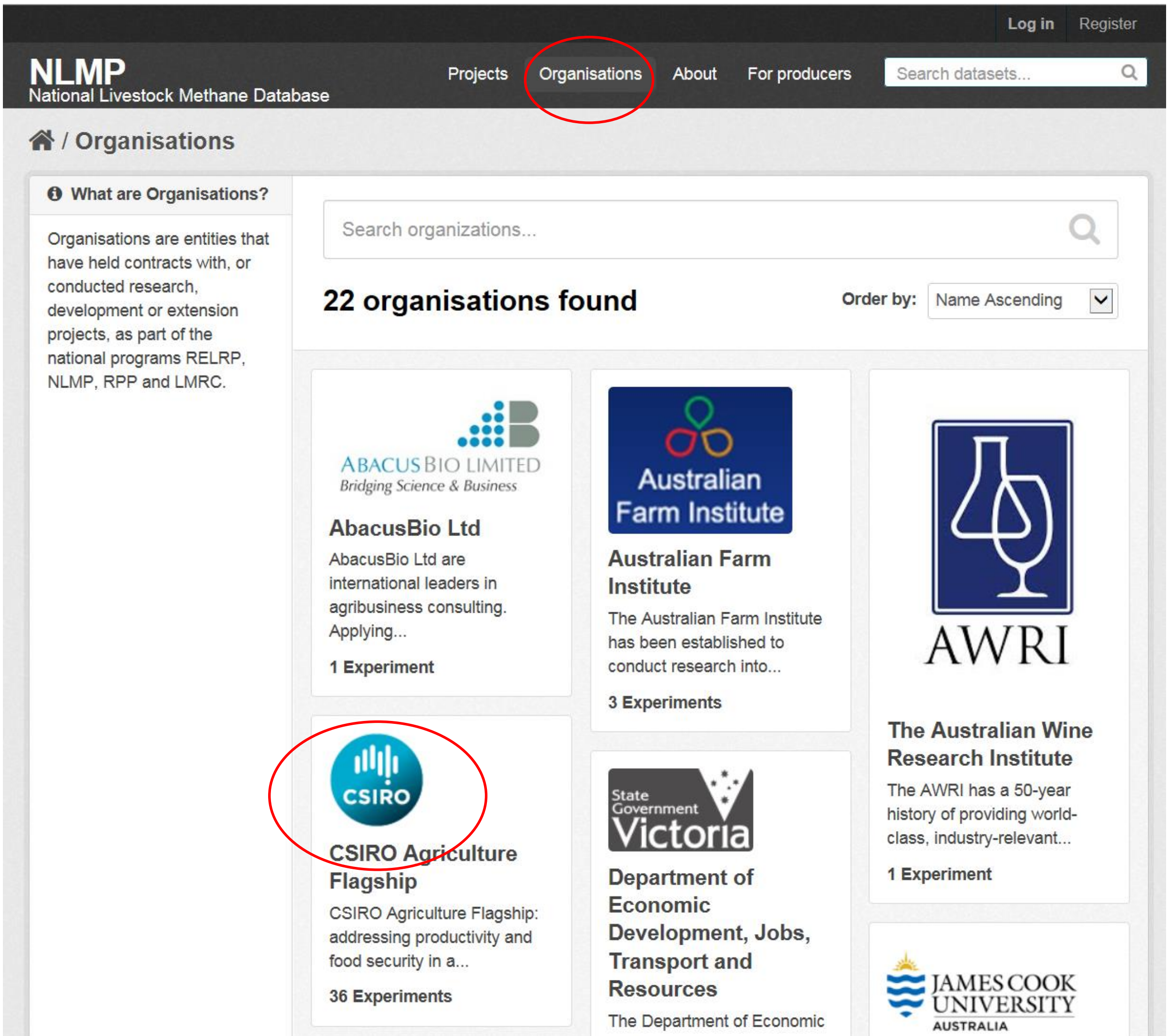


Figure 3. The Organizations page

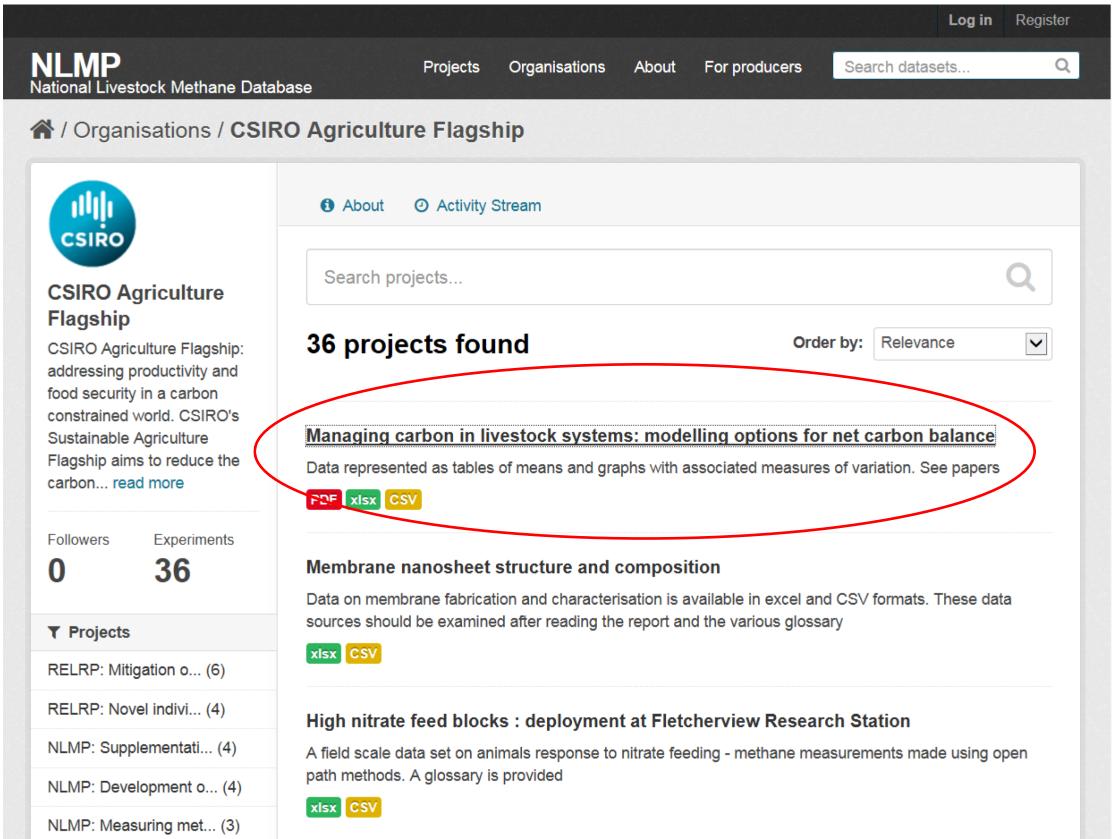


Figure 4. Projects found under the organization CSIRO

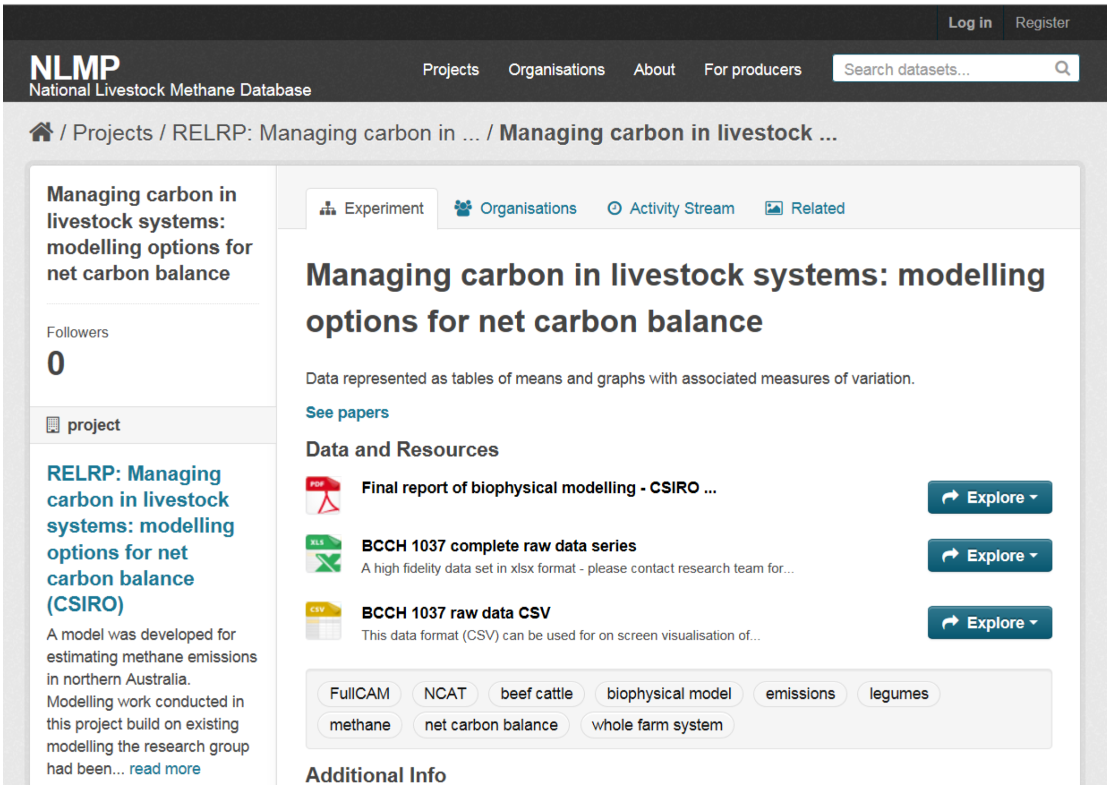
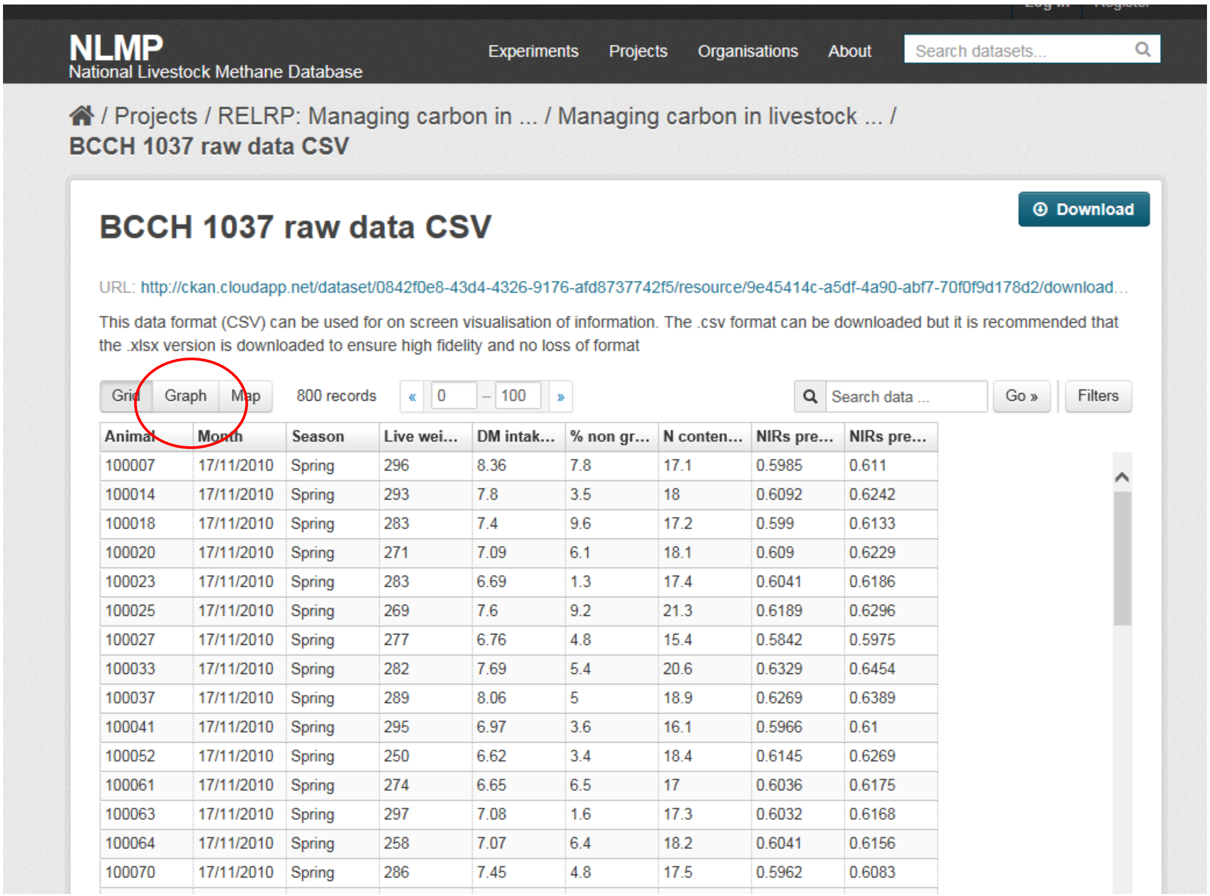


Figure 5. Experimental details found under the project Managing carbon in livestock systems

These files can be accessed and downloaded for further analysis and interrogation. In the example below the CSV file has been opened by clicking on the CSV icon (Figure 6).



Animal	Month	Season	Live wei...	DM intak...	% non gr...	N conten...	NIRs pre...	NIRs pre...
100007	17/11/2010	Spring	296	8.36	7.8	17.1	0.5985	0.611
100014	17/11/2010	Spring	293	7.8	3.5	18	0.6092	0.6242
100018	17/11/2010	Spring	283	7.4	9.6	17.2	0.599	0.6133
100020	17/11/2010	Spring	271	7.09	6.1	18.1	0.609	0.6229
100023	17/11/2010	Spring	283	6.69	1.3	17.4	0.6041	0.6186
100025	17/11/2010	Spring	269	7.6	9.2	21.3	0.6189	0.6296
100027	17/11/2010	Spring	277	6.76	4.8	15.4	0.5842	0.5975
100033	17/11/2010	Spring	282	7.69	5.4	20.6	0.6329	0.6454
100037	17/11/2010	Spring	289	8.06	5	18.9	0.6269	0.6389
100041	17/11/2010	Spring	295	6.97	3.6	16.1	0.5966	0.61
100052	17/11/2010	Spring	250	6.62	3.4	18.4	0.6145	0.6269
100061	17/11/2010	Spring	274	6.65	6.5	17	0.6036	0.6175
100063	17/11/2010	Spring	297	7.08	1.6	17.3	0.6032	0.6168
100064	17/11/2010	Spring	258	7.07	6.4	18.2	0.6041	0.6156
100070	17/11/2010	Spring	286	7.45	4.8	17.5	0.5962	0.6083

Figure 6. Visual of the raw data as a CSV file.

By Clicking on graph (left hand side immediately above the data) the user can build graphs of the relevant data they are interested in. The graph in Figure 6 shows that there is wide variation among animals in their selection for non-grass (legume) in the pasture. By hovering the mouse over the graph to provide the exact information for any one data point. Data can be downloaded to a excel file simply by clicking on the "Download" button.

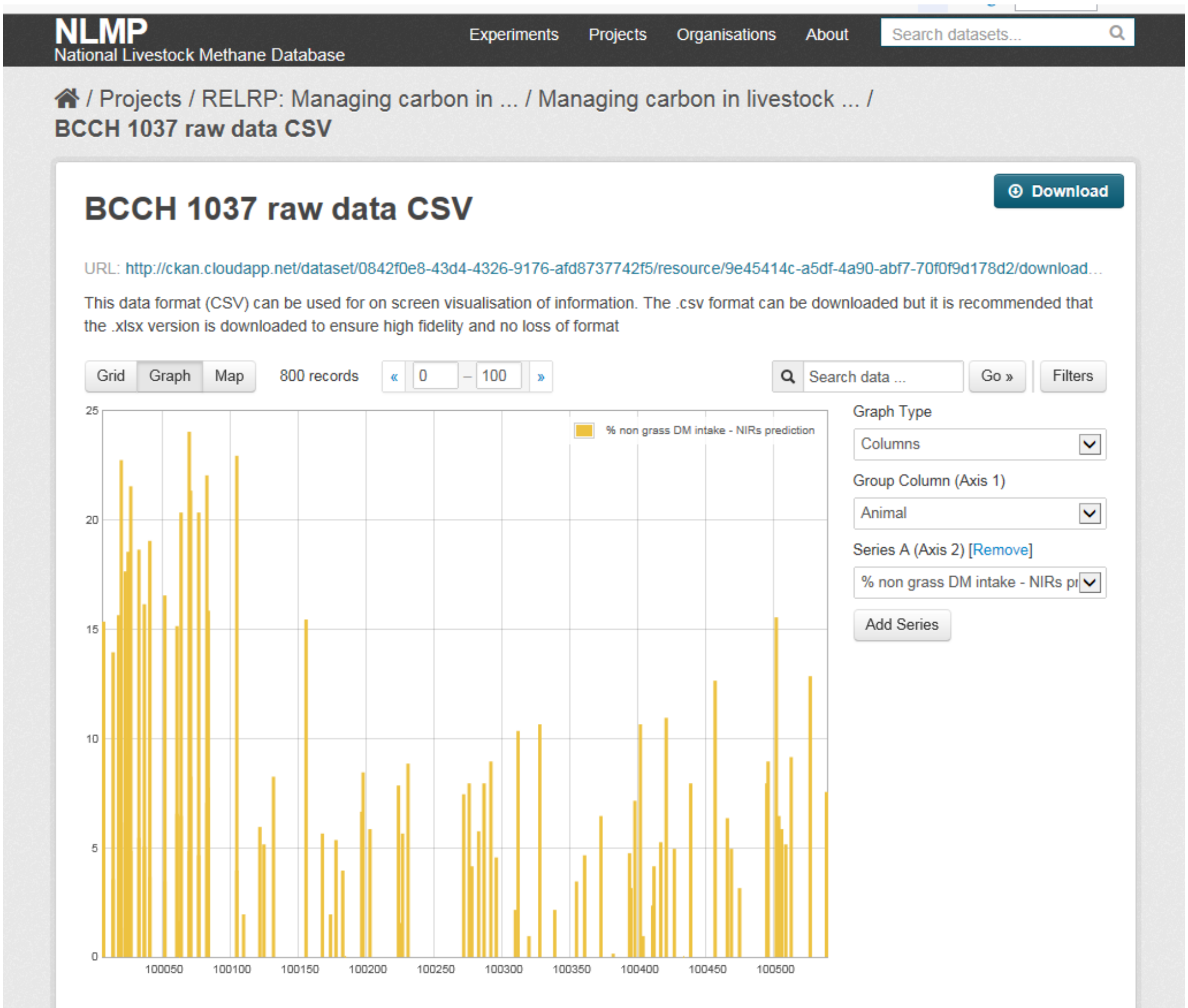
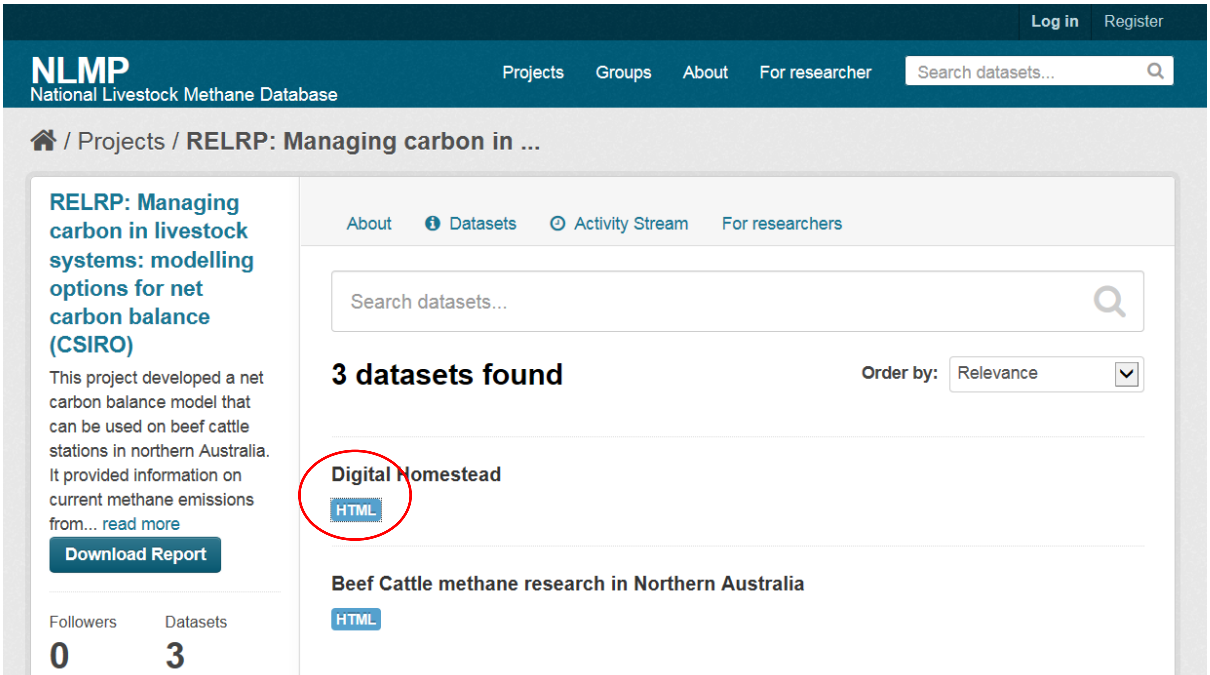


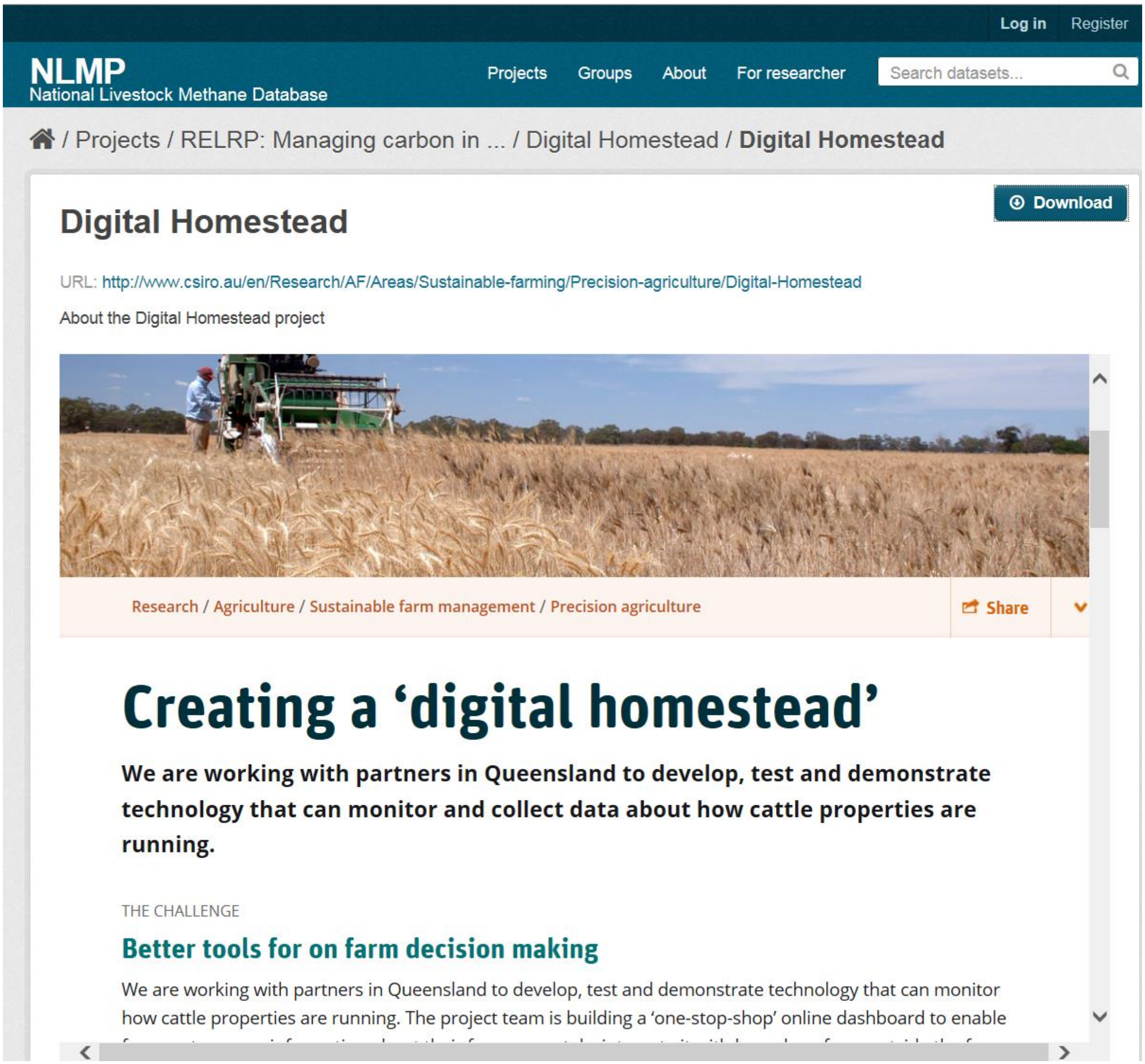
Figure 6. Graphical representation of the data from a CSV file.

4) Using the Producer button and links to external websites

Navigating in the Producer database is exactly the same, however the resources are different. For example in the project demonstrated above, Managing carbon in livestock systems: modelling options for net carbon balance, three datasets are found. Clicking on Digital Homestead links to a HTML file and a CSIRO website. In this way the user has direct access to relevant information stored in remote websites.



Log in
Register
NLMP
National Livestock Methane Database
Projects
Groups
About
For researcher
Search datasets...
/ Projects / RELRP: Managing carbon in ...
RELRP: Managing carbon in livestock systems: modelling options for net carbon balance (CSIRO)
This project developed a net carbon balance model that can be used on beef cattle stations in northern Australia. It provided information on current methane emissions from... read more
Download Report
Followers
0
Datasets
3
About
Datasets
Activity Stream
For researchers
Search datasets...
3 datasets found
Order by:
Relevance
Digital Homestead
HTML
Beef Cattle methane research in Northern Australia
HTML



Log in
Register
NLMP
National Livestock Methane Database
Projects
Groups
About
For researcher
Search datasets...
/ Projects / RELRP: Managing carbon in ... / Digital Homestead / Digital Homestead
Digital Homestead
Download
URL: http://www.csiro.au/en/Research/AF/Areas/Sustainable-farming/Precision-agriculture/Digital-Homestead
About the Digital Homestead project
Research / Agriculture / Sustainable farm management / Precision agriculture
Share
Creating a 'digital homestead'
We are working with partners in Queensland to develop, test and demonstrate technology that can monitor and collect data about how cattle properties are running.
THE CHALLENGE
Better tools for on farm decision making
We are working with partners in Queensland to develop, test and demonstrate technology that can monitor how cattle properties are running. The project team is building a 'one-stop-shop' online dashboard to enable

5) Links to scientific publications

In a similar manner, the user can access any scientific publications that relate to the research and have been nominated in the information upload. For example, the user can simply type in "papers' in the search box. This selects any experiments with attached papers. In this example the project "Influence of cold-pressed canola…) is brought up. Select the title to go to that experiment then select **Related**. If publication not open-source you will need to pay to see the have access to it, unless you have a subscription to this journal.

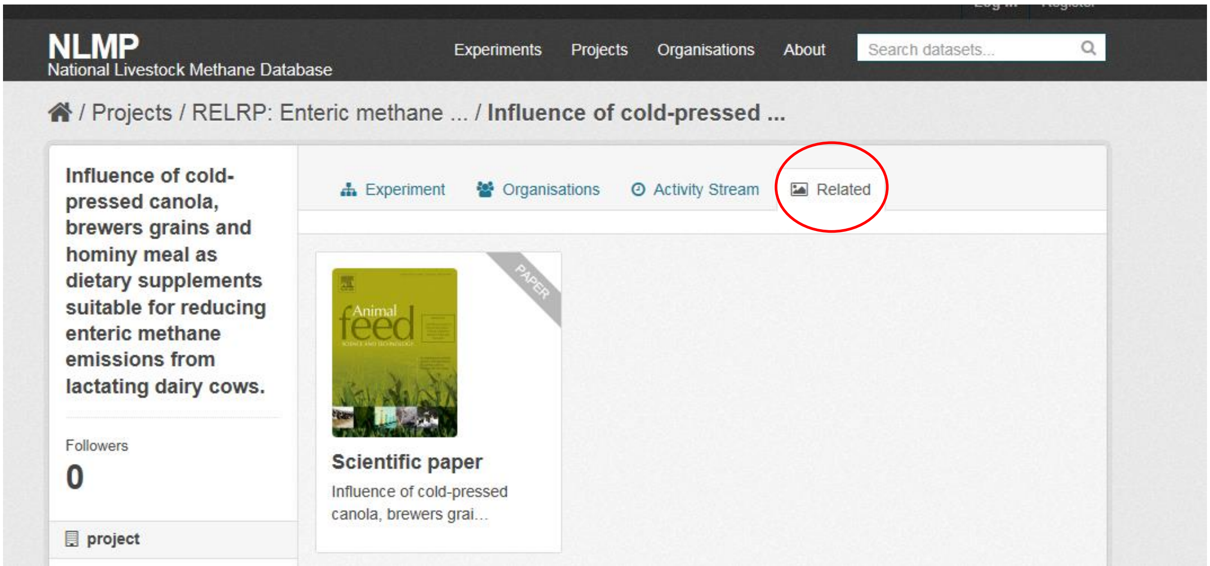


Figure 9. The link to a published paper that relates to the experiment.

Note: This guide was prepared in May 2015 and updated in October 2015. The guide was accurate at the time. Ongoing development of the database will alter some of the information and a level of intuition may be required to interpret the steps consistent with the current version of the database.

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