LAND AND WATER
www.csiro.au

Assessing the economic effect of CSG activity under different scenarios in NSW

Milestone 4

Final report of the '*Analysing Economic and Demographic Trajectories in NSW Regions Experiencing CSG Development*' Project

Tom Measham, Raymundo Marcos-Martinez, David Fleming
January 2018

CSIRO | Australia Pacific LNG | QGC | origin | Santos We have the energy. | NSW Government | Australian Government Department of Industry, Innovation and Science

Assessing the economic effect of CSG activity under different scenarios in NSW

ISBN (print): 978-1-4863-0958-0
ISBN (online): 978-1-4863-0959-7

The Gas Industry Social and Environmental Research Alliance (GISERA) undertakes publicly-reported research that addresses the socioeconomic and environmental impacts of Australia's natural gas industries. For further information visit gisera.csiro.au.

Citation

Measham, T., Marcos-Martinez, R., Fleming D. A. (2017) Assessing the economic effect of CSG activity under different scenarios in NSW: Report to the Gas Industry Social and Environmental Research Alliance (GISERA). CSIRO, Canberra.

Copyright

Important disclaimer

Contents

Figures

Tables

Acknowledgments

The authors thank Rod McCrea, Karin Hosking, Lavinia Poruschi and Dan O'Sullivan for helpful comments on earlier drafts of this report. This report was supported by the Gas Industry Social and Environmental Research Alliance (GISERA). GISERA is a collaboration between CSIRO, Commonwealth and state governments and industry established to undertake publicly-reported independent research. The purpose of GISERA is to provide quality assured scientific research and information to communities living in gas development regions focusing on social and environmental topics including: groundwater and surface water, biodiversity, land management, the marine environment, and socioeconomic impacts. The governance structure for GISERA is designed to provide for and protect research independence and transparency of research. Visit gisera.csiro.au for more information about GISERA's governance structure, projects and research findings.

Executive summary

This is the final report of the '*Analysing Economic and Demographic Trajectories in NSW Regions Experiencing CSG Development*' Project. The report details methods for calculating future benefits and impacts under different scenarios for the CSG industry in NSW and presents the outcomes from each scenario. The economic research underpinning the method was presented in Milestone 3 which presented a historic analysis of the economic impact that the emerging CSG industry had on rural NSW regions during the period 2001–2011. Milestone 3 report demonstrated that during this early phase of the industry, regions experiencing CSG industry activity had 6% higher median weekly incomes than regions without CSG activity (Marcos-Martinez et al. 2017). In this final report, we have developed projections which use the same core economic modelling as Milestone 3, but rather than look back at measuring past effects, we look forward to consider what could happen under different hypothetical scenarios. The scenarios presented in this report do not imply that CSG development could or will occur in any particular region in NSW.

Compared to Queensland, CSG activity in NSW is small and, even if the Narrabri project proceeds, it would be small relative to the CSG industry in Queensland. As reference points for preparing projections in NSW, the report draws on historic drilling rates within NSW. The industry has developed slowly from an early rate of around 10 new wells per year in 2000 to a maximum of around 130 new wells per year in 2009 then subsequently reduced to around 16 wells per year in 2014. As a point of comparison, the maximum number of wells drilled in a single year in Queensland reached around 1,600 in 2013–2014.

Income effects

To estimate potential future income effects of CSG in NSW, three scenarios were analysed:

- Scenario 1. Business as usual. Continuation of observed trend of reduced rates of drilling – from the high of 2009 to the low rates a few years later will continue.
- Scenario 2. Mid-range CSG activity. Increasing gas demand translates into new CSG activity at average 2010–2014 levels.
- Scenario 3. Above mid-range CSG activity. Increasing gas demand reactivates CSG activity in the region at maximum 2010–2014 levels.

Continuation of existing trends under the 'business as usual' scenario suggests that the income effect of CSG activity could gradually reduce to 2035. This is motivated by the decommissioning of production wells over time and the trend of relatively few or no wells drilled in CSG regions.

Under the 'mid-range' scenario around 33 new wells would be drilled per year to 2035. This scenario assumes that increasing gas demand could result in new CSG activity in the region. Under different levels of increased gas demand (and high energy prices), between 660 and 800 new wells in total could be drilled between 2020 and 2035. Under this scenario, regions in which CSG development occurred would be expected to have around 6–7% higher incomes than regions without CSG, after

adjusting for other changes in regional economies as set out in Milestone 3 (Marcos-Martinez et al. 2017).

The 'above mid-range' scenario also assumes that potential changes in demand for gas could result in new CSG activity in the State. Under this scenario, between 1800 and 2240 wells in total could be drilled between 2020 and 2035. If the industry were to proceed at this rate, then those regions in which CSG activity occurred would be expected to have incomes around 7–8% higher than regions without CSG activity.

Employment effects

Econometric modelling presented in Milestone 3 tested for statistically significant differences in economic indicators between regions with past CSG development and a control group of comparable regions. There was no statistically significant finding of employment multiplier effects in regions with past CSG development compared to the control group. This also reflects the relatively small size of the CSG industry in NSW compared to Queensland where there are employment multiplier effects associated with the CSG industry (Fleming & Measham 2015).

By contrast, evidence was found of statistically significant differences in median personal income and median family income which were both around 6% higher in NSW regions which had experienced previous CSG industry activity compared to the control group. These higher incomes were found to be independent of other factors such as changes in agricultural profitability, human capital and commodity prices. This suggests that small family income effects may be experienced in regions with relatively small or isolated CSG industry activities, while employment multiplier effects are associated with more expansive and widespread CSG activity.

This final report concludes that, if CSG exploration and production activity were to continue past trends in NSW, then the income effects documented in Milestone 3 could gradually disappear. By contrast, if the industry were to proceed at a steady rate, drilling around 660 to 800 wells by 2035, then those regions in which that CSG activity occurred would be expected to have approximately 6–7% higher incomes than regions without CSG activity. This scenario provides a potential reference point for the proposed Narrabri Gas project in NSW which, if it were to proceed as planned, would likely involve around 850 new wells. Finally, if the gas industry were to develop at the maximum observed annual drilling rate for the State, i.e. between 1800 and 2240 total new wells to 2035, then the difference in family income could increase to around 7–8% in those regions in which the activity occurred compared to regions where no CSG occurred.

1 Introduction

Coal seam gas activity has the potential to impact economic growth, labour markets, and demographic and environmental conditions in rural areas (Sherval & Hardiman 2014; Hamawand et al. 2013; Batley & Kookana 2012; Measham & Fleming 2014; Fleming & Measham 2015). Globally, the development of the CSG industry is expected to continue as gas consumption increases in the transition to cleaner sources of energy production (AEMO 2016; Lacey & Lamont 2014). However, operational challenges generated by social and regulatory factors may limit or stop the development of CSG activities at local or regional scales (Lacey & Lamont 2014). Empirical assessments of the economic effects of CSG development could inform the selection of CSG activity levels that balance competing interests.

The findings presented in this report build on the earlier reports prepared for this project *Analysing Economic and Demographic Trajectories in NSW Regions Experiencing CSG Development*. Regions with past CSG activity and a comparable control group of regions were presented in Milestone 2 (Measham & Fleming 2017) along with detailed baseline demographic and economic data for focal regions such as Narrabri. Milestone 2 noted a difference in the median incomes for regions which experienced CSG industry activity during the baseline assessment period of 2001–2011 compared to regions without CSG industry activity.

Building on the statistical analysis of regional family income trajectories observed in NSW during the period 2001–2011 documented in Milestone 3 (Marcos-Martinez et al. 2017), we applied scenario evaluation to identify potential effects of alternative levels of CSG activity. The analysis was applied to regions that experienced CSG activity in NSW during the period 2001–2011 and a counterfactual group of relevant non-CSG regions (Measham & Fleming 2017). We relied on a comprehensive dataset of spatiotemporal economic, environmental and demographic parameters coupled with econometric modelling (Spatial Panel Data Models) to estimate the impact of the CSG industry on median family income. The econometric analysis was then used to evaluate potential economic implications of CSG activity in NSW under three different scenarios:

1. Business as usual.
2. Increasing gas demand translates into new CSG activity at average 2010–2014 levels.
3. Increasing gas demand reactivates CSG activity in the region at maximum 2010–2014 levels.

This scenario analysis complements the baseline socioeconomic assessment and the statistical analysis documented in Milestones 2 and 3 of this project.

2 Empirical statistical model

The assessment of the economic effects of different levels of CSG activity was based on a spatial econometric model of median family income dynamics calibrated with NSW data observed during the period 2001–2011. The model approximates the effect of CSG activity by comparing changes in median income indicators in regions that had experienced CSG activities (24 SA2 regions) relative to the income trajectories observed in regions with similar socioeconomic characteristics but without any CSG industry presence (control group) – see Milestone 2 and 3 reports for summary statistics of the matched groups (Measham & Fleming 2017; Marcos-Martinez et al. 2017).

The population density distribution across regions with prior CSG activity was used to select 114 SA2 regions as a control group. Population density was used as a matching variable since such parameter is a proxy of the size of local goods and services supply and demand, degree of infrastructure development, agricultural land conversion pressure and declining farm income (Muyanga & Jayne 2014; Josephson et al. 2014; Fleming & Measham 2015).

The estimated model assumes that regional and temporal income variability in the study areas were influenced by factors that impact crop and livestock productivity (e.g. climate, land quality), returns to human and economic capital (e.g. job experience, education, access to services/infrastructure), and returns to other non-CSG mining activities (e.g. oil and coal prices). To account for such factors we collected a comprehensive dataset of spatiotemporal information on average climate, topography, age, education, employment, indicators of access to services and non-CSG mining activity (i.e. wells for traditional mining activity such as coal, gemstones or oil exploration wells) at the SA2 level and export coal prices (Table 1).

Statistical methods were applied to control for variables not included in the model and for spatial error correlation. Specifically, family income effects of CSG activity were estimated using a spatial panel with random effects model of the form: $\ln(\mathbf{Y}) = \boldsymbol{\beta}'\ln(\mathbf{X}) + \alpha\mathbf{z} + \mathbf{u}$, where ln represents the natural log, $\mathbf{Y}$ is a vector of weekly median family income data observed at the SA2 region during the years 2001, 2006 and 2011; $\mathbf{X}$ is a matrix that includes variables that influence agricultural productivity and returns to human capital; $\mathbf{z}$ is a binary vector of identifiers for regions that experienced CSG activity during the study period; $\boldsymbol{\beta}$ is a vector of coefficients that approximate the effect of each explanatory variable on family income; α is the coefficient of an indicator variable for regions influenced by CSG activity that captures the family income effect of CSG activity; and $\mathbf{u}$ is an error component that accounts for effects of spatially correlated unobserved variables, unobserved regional differences (i.e. random effects) and for random errors. See Marcos-Martinez et al. (2017) for an extended description of the methodology.

Spatial and temporal changes in personal income are highly correlated with changes in family income and therefore our analysis was focused on the latter. The regression results for median weekly family income are shown in Table 2 and discussed in Milestone 3 of this project (Marcos-Martinez et al. 2017). Overall, estimates for the CSG region variable indicated that, on average, regions in the treatment group had 6.31% higher family income than regions in the control group over the period 2001 to 2011, controlling for other regional characteristics.

3 Scenarios of CSG activity and family income trajectories

The econometric analysis indicates that, everything else constant, those regions with past CSG activity had around 6% higher median income than non-CSG regions during the period 2001–2011. A one percent increase in CSG well density (equivalent to around four new wells during the study period) was associated with a negligible and not statistically significant effect on median family income. Around 75% of the CSG wells drilled between 2001 and 2011 were concentrated in 25% of the SA2 regions that experienced CSG drilling during the study period, with most drilling occurring after 2006. The low spatial and temporal variability of drilling activity could explain the negligible results for the CSG well density parameter.

For scenario assessment, we assume that the magnitude and direction of the effect of both CSG activity and well density on median weekly family income continue to hold into the future, and that future CSG activity does not occur outside of those SA2 regions in which CSG activity had occurred in the past (Figure 2). Under these assumptions we assessed the income effects of three scenarios of CSG activity:

- Scenario 1. Business as usual. The industry continues its current trend of declining CSG activity in NSW.
- Scenario 2. Increasing gas demand reactivates CSG activity in the study region at historical averages.
- Scenario 3. Increasing gas demand reactivates CSG activity in the study region at maximum historical levels.

3.1 Scenario 1. Business as usual

The number of new CSG wells drilled in the CSG regions reached a maximum of 131 in 2009 (Fig. 1). By 2014 the drilling of new wells had declined to levels observed in 2000 and 52% of the wells drilled during the period 2001–2014 had been permanently sealed (Fig. 2). Around 12% of the CSG wells remained under production, concentrated in only two SA2 regions (Douglas Park–Appin and Gloucester, NSW). If the observed CSG industry trend towards zero, or highly spatially localised activity, continued, the statistical difference on median family income among CSG and non-CSG regions (Marcos-Martinez et al. 2017) could gradually disappear.

Table 1. Average region specific characteristics related to land and human capital productivity

Variable	Description and source	Unit
Dependent variables		
Family income	Median total family income (weekly) (ABS 2011).	2011/12 AUD
Average soil and topographic characteristics		
Bulk density	Upper 30 cm soil layer bulk density (ACLEP 2014).	Mg/m^3
Clay content	Upper 30 cm soil layer % clay content (ACLEP 2014).	%
Slope	Topographic gradient.	degree
Elevation	Metres above sea level (Gallant et al. 2011).	metres
Average climatic conditions		
Rainfall	Five-year moving averages of annual rainfall (Australian Bureau of Meteorology 2015).	mm
Rainfall variability	Five-year moving standard deviations of annual rainfall.	mm
Maximum temperature	Five-year moving averages of annual average maximum temperature (Australian Bureau of Meteorology 2015).	^oC
Maximum temperature variability	Five-year moving standard deviations of annual average maximum temperature.	^oC
Socioeconomic factors		
Age and age squared	Median age of persons (ABS 2011).	year
Higher education	Percent of population aged 15 years and over with at least a bachelor degree.	%
Agricultural employment	Percent employed in agriculture.	%
Mining employment	Percent employed in mining (including gas extraction).	%
Manufacturing employment	Percent employed in manufacturing.	%
Remoteness accessibility index	The Accessibility and Remoteness Index of Australia (ARIA) is based on the road distance from populated localities to urban centres offering public and private services (GISCA 2001).	score
CSG region	Categorical variable to indicate regions with past coal seam gas activity (NSW Division of Resources and Energy 2015).	binary
CSG well density	CSG wells per 100 square kilometres. Well density was included to control for the different effect that wells have in SA2 of different area.	Wells per 100 km^2
Non-CSG well density	Number of drill holes for non-CSG mining (e.g. oil or minerals exploration) per 100 square kilometres.	Wells per 100 km^2
Thermal coal price	Average export unit value $/ton of thermal coal (Office of the Chief Economist 2014).	2011/12 AUD

Note: SA2 averages of spatial data were computed using zonal statistics in ArcMap 10.4. See Milestone 3 report (Marcos-Martinez et al. 2017) for summary statistics and spatial resolution.

Table 2. Percent change in family income associated with a 1% change in each continuous variable relative to regions in which no CSG development occurs.

Parameters	Estimate	Std. Error	t-value	Pr(>|t|)	
CSG activity					
CSG region[a]	6.3085	2.8308	2.2285	0.0264	**
CSG well density	0.0026	0.0017	1.5318	0.1256	
Average soil and topographic characteristics					
Bulk density	0.3278	0.1528	2.1460	0.0319	**
Clay content	–0.0307	0.0358	–0.8577	0.3911	
Elevation	0.0381	0.0153	2.4954	0.0126	**
Slope	0.0033	0.0167	0.2001	0.8414	
Average climatic conditions					
Rainfall	–0.1253	0.0282	-4.4494	0.0000	***
Rainfall variability	0.0003	0.0079	0.0403	0.9679	
Maximum temperature	–0.0366	0.1343	–0.2725	0.7852	
Maximum temperature variability	–0.0576	0.0111	-5.1878	0.0000	***
Socioeconomic factors					
Higher education	0.1772	0.0171	10.3756	0.0000	***
Median age	4.4563	0.1330	33.5113	0.0000	***
Median age squared	–2.5146	0.1048	–24.0046	0.0000	***
Remoteness/accessibility index	–0.1006	0.0197	–5.1178	0.0000	***
Agricultural employment	–0.0256	0.0125	–2.0563	0.0398	**
Mining employment	–0.0022	0.0028	–0.7895	0.4298	
Manufacturing employment	–0.0513	0.0146	–3.5077	0.0005	***
Thermal coal price	0.2931	0.0404	7.2616	0.0000	***
Non-CSG well density	–0.0007	0.0011	–0.6260	0.5313	
Intercept	8.8663	0.5549	15.9794	0.0000	***
Error variance parameters					
Var. of unobserved heterogeneity / Var. of random disturbances	6.4219	1.1052	5.8106	0.0000	***
Spatial error correlation	0.2880	0.0640	4.5007	0.0000	***
R-squared	0.9760				

Significance codes: '***' 0.01 '**' 0.05. All variables, including the dependent variable, were transformed to their natural logarithms, which allows to interpret the estimates as percent changes, e.g., the percent different in family income to a 1% change in the variable. Variables with '[a]' where not log-transformed as they are binary variables, so their estimate should be interpreted as percent change after the binary variable receiving a value of one instead of zero. Number of observations = 414 (114 control regions, 24 treatment regions, and three periods). Source: Marcos-Martinez et al. (2017)

The income effect of CSG activity was documented with information observed between 2001 and 2011, a period in which CSG drilling occurred across 24 SA2 regions at levels higher than those observed in recent years (2012–2014) (Figure 2). If CSG activity stops or concentrates in a small number of regions, then the CSG income effect would only apply to those regions still experiencing CSG activity. If the spatiotemporal pattern of CSG activity in rural NSW regions deviates significantly from the pattern observed during the period 2001–2011 (for instance through a ban on new drilling activity), then the statistical model would need to be re-estimated with a re-defined CSG regions (i.e. the division of CSG and non-CSG regions shown in Figure 2 would require an update).

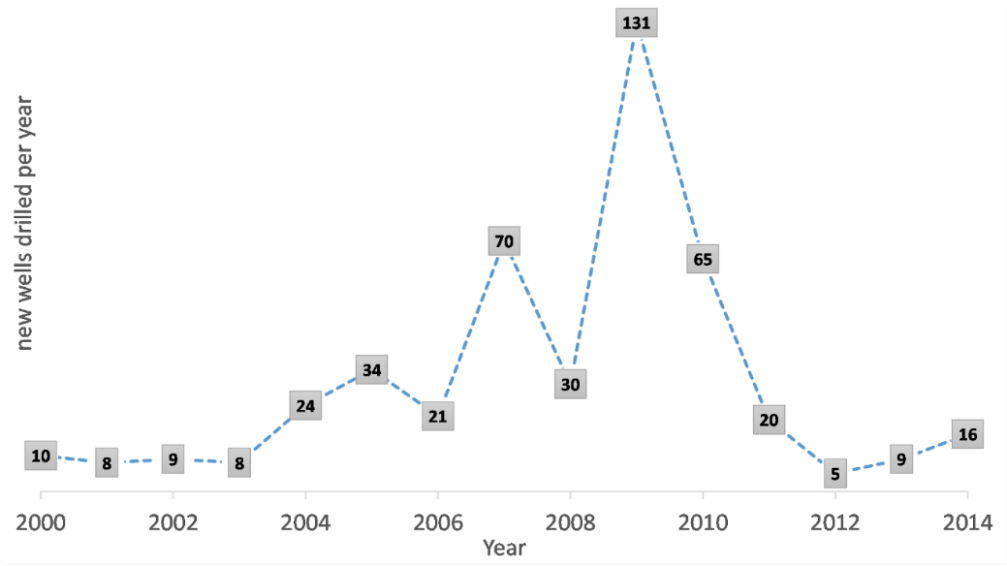

Figure 1. Wells drilled per year (2000–2014)

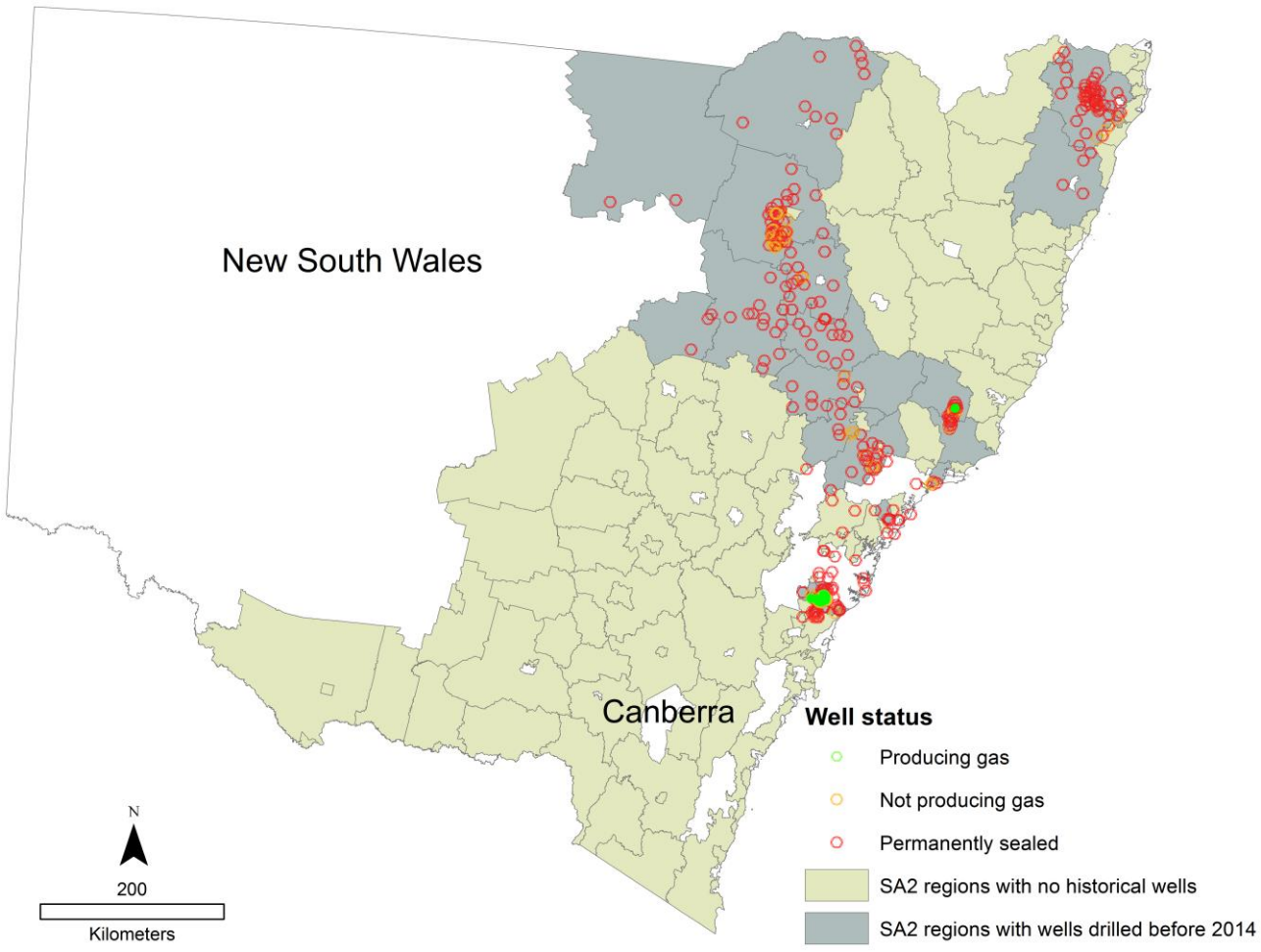

Figure 2. Status of past CSG wells drilled during the period 2000–2014 in Statistical Local Areas (SA2) across NSW.

3.2 Scenario 2. Increasing gas demand translates into new CSG activity at average 2010–2014 levels

The 2016 National Gas Forecasting Report (NGFR) (AEMO 2016) projects Australian gas consumption for all regions and sectors from 2016 to 2036 under three scenarios:

- Weak. Low population and economic growth and increased energy efficiency.
- Neutral. Average trend in population and economic growth and medium energy efficiency uptake.
- Strong. Strong population and economic growth and high energy efficiency uptake.

Increases in gas demand without increases in supply could result in higher energy prices for all sectors, potentially resulting in regulatory and social licence changes in the CSG industry. Based on the share of NSW energy consumption relative to the country level consumption in 2014–15 (Department of Industry 2016), we assume that a 1% increase in projected gas demand under the NGFR outlooks results in a 0.25% increase in new CSG activity (i.e. new wells) in the study area. The rates of change were applied to the average number of new wells observed per year during the period 2010–2014 (23 wells per year). This period was selected under the assumption that it better approximates current market, institutional and social conditions related to the CSG industry in the study area.

Based on average rates of well retirement observed during the period 2001–2014 we assume that 3.42% of the existing CSG wells are retired per year. Under these assumptions the average number of new CSG exploration, appraisal or production wells is expected to oscillate around 33 new wells per year on average during the period 2015–2035 (Fig. 3a). This could result in between 660 and 800 new wells by 2035 (Fig. 3b). The increasing level of CSG activity (approximated by past well density values) under the weak, neutral, and strong gas demand outlooks was associated with, on average, 6.68%, 6.71% and 6.75% higher weekly median family income to 2035 relative to regions without CSG activity.

3.3 Scenario 3. Increasing gas demand reactivates CSG activity in the region at maximum 2010–2014 levels

This scenario also assumes that the rates of change for the different gas demand outlooks (AEMO 2016) result in similar rates of change in CSG activity in NSW. However, the changes are applied to the maximum annual drilling level observed during the period 2010–2014 (65 new wells in 2010). Under this scenario the average number of new wells per year for the period 2015–2035 is projected to be 84, 94 and 105 wells for the weak, neutral and strong outlooks, respectively (Fig. 4a). This would result in around 1,800, 2,000 and 2,240 wells drilled in the region from 2000 to 2035 (Fig 4b). By 2035, the higher well density and continuing CSG activity would result in 7.35%, 7.46%, and 7.57% higher weekly median family income in those regions in which CSG activity occurred under the weak, neutral and strong CSG activity scenarios. On average, this scenario results in a 0.75% higher median weekly family income level than the Scenario 2 projections. The higher number of new wells projected under this scenario does not translate into a larger income effect due to the small well density coefficient estimate.

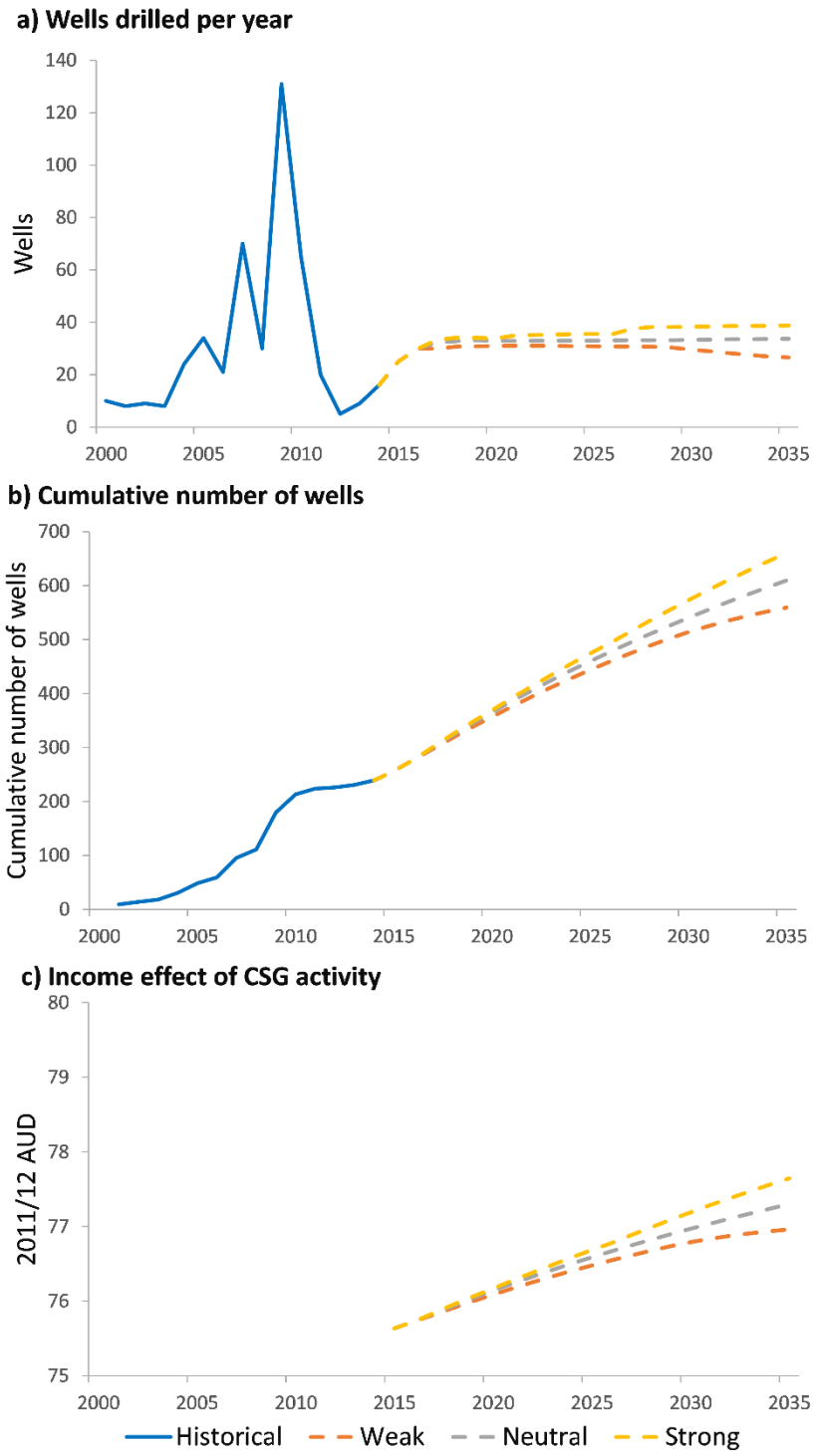

Figure 3. Scenario 2: Changes in CSG activity relative to 2010–2014 averages

a) Wells drilled per year follow historical averages. b) Cumulative number of wells accounting for well retirement. c) Difference in median weekly family income between CSG and non-CSG regions. Based on the 2016 National Gas Forecasting Report projections of Australian gas consumption (AEMO 2016), the weak, neutral, and strong scenarios are linked to low, average, and strong population and economic growth and energy efficiency uptake respectively.

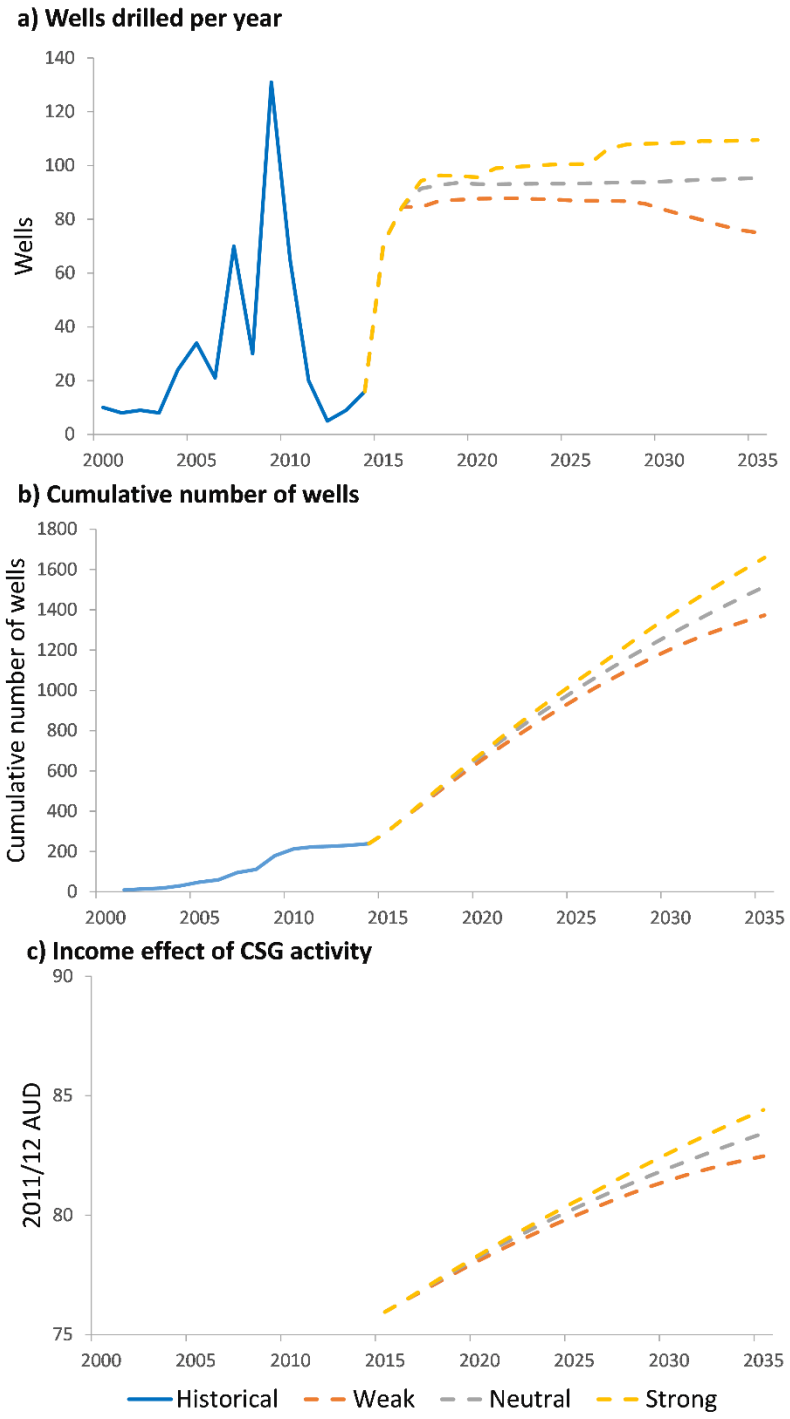

Figure 4. Scenario 3: Changes in CSG activity using as a baseline the maximum number of wells observed during the period 2010–2014

a) Wells drilled per year follow historical averages. b) Cumulative number of wells accounting for well retirement. c) Difference in median weekly family income between CSG and non-CSG regions. Based on the 2016 National Gas Forecasting Report projections of Australian gas consumption (AEMO 2016), the weak, neutral, and strong scenarios are linked to low, average, and strong population and economic growth and energy efficiency uptake respectively.

4 Discussion and concluding remarks

According to the gas field development plan of the Narrabri Gas project a maximum of 850 new CSG wells could be in operation in the Narrabri region between 2018 and 2043. CSG activity under Scenario 2 (changes relative to the average 2010–14 CSG activity) represent on average 86% of the size of the Narrabri project (735 new wells). Scenario 3 corresponds to 2.4 times more new wells than the Narrabri project. However the average number of wells drilled per year is 30% less than the maximum observed in 2009 in NSW and only 6% of the maximum number of wells drilled in a year in Queensland (1634 in 2013–14) (Department of Natural Resources and Mines 2017). If additional CSG activity only occurs as part of the Narrabri Gas project we would expect spatially heterogeneous changes in the income effect estimated during the period 2001–2011. Higher income around the Narrabri region would be expected to continue but the CSG income effect could disappear in areas where CSG activity stops.

A strong assumption was made to link projected changes in domestic gas demand with changes in CSG activity in NSW. Specifically, we assumed that each 1% change in projected domestic gas demand would result in a 0.25% change in CSG well drilling. It is likely that demand shocks will be covered by increased supply first from regions which already had established conventional gas or CSG industries or with social licence. In addition, if future levels of CSG activity deviate significantly from the patterns observed during the period 2000–2011 the statistical analysis would not provide an accurate estimation of the potential impacts of the industry. Regardless of this, the analysis provided above and the estimations obtained from the scenarios reflect what 'on average' we could expect given the different scenarios presented for potential future CSG activity in NSW.

Although we have based the scenarios on statistical analysis of observed findings in the past, the projections we present in this report extrapolate beyond the normal timeframe for statistically based projections. We also assumed that the direction and magnitude of the well density coefficient will continue to hold into the future despite its lack of statistical significance. Therefore the projections are presented here as hypothetical outcomes over a limited subset of possible futures rather than statistical predictions. Statistically based determination of alternative scenarios was not implemented due to the lack of sufficient historical data to provide reliable forecasting functions for the projected period. Since the employment multiplier analysis indicated no statistically significant effect of CSG activity (Marcos-Martinez et al. 2017) employment projections were not modelled.

This is the final report from the *Analysing Economic and Demographic Trajectories in NSW Regions Experiencing CSG Development* Project. The authors emphasise that the results presented in this report are intended to inform future research on the economies of regions experiencing CSG industry activity in New South Wales, if the industry proceeds.

Glossary

Term	Explanation
CSG	Coal seam gas
CSG regions	Regions in the State of New South Wales where CSG production, profiling and exploration wells were registered with the NSW Government during the period 2001–2011
Forecasting function	Statistical equation used to project futures states of a dependent variable based on projected values of explanatory variables
Income dynamics	Spatial and temporal changes in median family or personal income across SA2 regions.
Non-CSG well	Drillholes excavated for non-CSG mining (e.g. oil or coal exploration, profiling or production).
NSW	State of New South Wales
SA2	Statistical Area level 2 are locations defined by the Australian Bureau of Statistics for the reporting of social and economic data. SA2 purpose is to delimit communities that interact socially and economically, and have an average size of about 10,000 persons.
Spatial panel data	Data containing time series observations for a number of spatial units (e.g. SA2 regions).
Spatial regression model	Statistical analysis of the effect of explanatory variables (X) on a dependent variable (Y) where X, Y or both are spatially explicit. It controls for correlated error terms with nearby areas.
Spatial weights matrix	A matrix representation of the spatial relationships (dependence) that exists across the units of analysis (SA2 regions), which is used in spatial regression
Unobserved heterogeneity	Factors that vary across regions for which data is not readily available to include in a statistical model (e.g. farmers' experience on agricultural production).

References

ABS, 2011. T02 Selected medians and averages. Available at: http://stat.data.abs.gov.au/Index.aspx?DataSetCode=ABS_CENSUS2011_T02.

ACLEP, 2014. National soil data provided by the Australian Collaborative Land Evaluation Program. Available at: http://www.asris.csiro.au/themes/NationalGrids.html.

AEMO, 2016. *National gas forecasting report for Eastern and South-eastern Australia*,

Australian Bureau of Meteorology, 2015. Climate Data Online. Available at: http://www.bom.gov.au/climate/data/ [Accessed September 1, 2015].

Batley, G.E. & Kookana, R.S., 2012. Environmental issues associated with coal seam gas recovery: managing the fracking boom. Available at: http://www.publish.csiro.au/en/pdf/EN12136 [Accessed September 14, 2017].

Department of Industry, I. and S., 2016. *Australian Energy Update 2016*, Canberra. Available at: https://industry.gov.au/Office-of-the-Chief-Economist/Publications/Documents/aes/2016-australian-energy-statistics.pdf.

Department of Natural Resources and Mines, Q., 2017. *Queensland's petroleum and coal seam gas. 2015 - 2016.*, Available at: https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0008/1237742/qld-petroleum-coal-seam-gas-2017.pdf.

Fleming, D.A. & Measham, T.G., 2015. Local economic impacts of an unconventional energy boom: the coal seam gas industry in Australia. *Australian Journal of Agricultural and Resource Economics*, 59(1), pp.78–94. Available at: http://doi.wiley.com/10.1111/1467-8489.12043.

Gallant, J. et al., 2011. STRM-derived 3 Second Digital Elevation model Version 1.0. Available at: http://www.ga.gov.au/metadata-gateway/metadata/record/72760/.

GISCA, 2001. Accessibility/Remoteness Index of Australia (ARIA). Available at: http://data.daff.gov.au/anrdl/metadata_files/pa_aria_r9s___00312a00.xml.

Hamawand, I., Yusaf, T. & Hamawand, S.G., 2013. Coal seam gas and associated water: A review paper. *Renewable and Sustainable Energy Reviews*, 22, pp.550–560. Available at: http://ac.els-cdn.com/S1364032113001329/1-s2.0-S1364032113001329-main.pdf?_tid=ec86115a-990d-11e7-9b41-00000aacb35d&acdnat=1505367256_059cb2992101c59de2ff2fd3bbe28279 [Accessed September 14, 2017].

Josephson, A.L., Ricker-Gilbert, J. & Florax, R.J.G.M., 2014. How does population density influence agricultural intensification and productivity? Evidence from Ethiopia. *Food Policy*, 48, pp.142–152. Available at: http://linkinghub.elsevier.com/retrieve/pii/S030691921400044X [Accessed August 16, 2017].

Lacey, J. & Lamont, J., 2014. Using social contract to inform social licence to operate: An application in the Australian coal seam gas industry. *Journal of Cleaner Production*, 84(1), pp.831–839. Available at: http://ac.els-cdn.com/S0959652613008111/1-s2.0-S0959652613008111-main.pdf?_tid=7ec69372-990f-11e7-8f22-00000aab0f02&acdnat=1505367930_6aa764077c539d3cb25f2355142aa544 [Accessed September 14, 2017].

Marcos-Martinez, R. et al., 2017. *Assessing linkages between regional economic indicators and CSG industry activity in NSW 2001-2011*, Canberra.

Measham, T.G. & Fleming, D.A., 2017. *Economic baseline for NSW CSG regions: Report to the Gas Industry Social and Environmental Research Alliance (GISERA)*, Canberra.

Measham, T.G. & Fleming, D.A., 2014. Impacts of unconventional gas development on rural community

decline. *Journal of Rural Studies*, 36, pp.376–385. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0743016714000485 [Accessed August 16, 2017].

Muyanga, M. & Jayne, T.S., 2014. Effects of rising rural population density on smallholder agriculture in Kenya. *Food Policy*, 48, pp.98–113. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0306919214000402 [Accessed August 16, 2017].

NSW Division of Resources and Energy, 2015. Drillholes and wells location. Available at: http://dwh.minerals.nsw.gov.au/CI/warehouse [Accessed August 16, 2017].

Office of the Chief Economist, 2014. *Resources and Energy Statistics 2014*, Canberra.

Sherval, M. & Hardiman, K., 2014. Competing perceptions of the rural idyll: responses to threats from coal seam gas development in Gloucester, NSW, Australia. *Australian Geographer*. Available at: http://www.tandfonline.com/doi/abs/10.1080/00049182.2014.899028 [Accessed September 1, 2017].

CONTACT US

t 1300 363 400
+61 3 9545 2176
e csiroenquiries@csiro.au
w www.csiro.au

FOR FURTHER INFORMATION

Helen Beringen
t +61 7 4753 8517
e gisera@csiro.au
w gisera.csiro.au

AT CSIRO, WE DO THE EXTRAORDINARY EVERY DAY

We innovate for tomorrow and help improve today – for our customers, all Australians and the world.

Our innovations contribute billions of dollars to the Australian economy every year. As the largest patent holder in the nation, our vast wealth of intellectual property has led to more than 150 spin-off companies.

With more than 5,000 experts and a burning desire to get things done, we are Australia's catalyst for innovation.

CSIRO. WE IMAGINE. WE COLLABORATE. WE INNOVATE.